

SHEET-METAL WORK

INCLUDING METAL SPINNING

DEALING WITH CUTTING, FORMING, BENDING,
FOLDING, WHEELING, BEADING, SWAGING,
MECHANICAL JOINTING, WELDING AND
SPINNING AS APPLIED TO SHEET METALS

*Prepared by a Staff of Technical
Experts under the direction of*

E. MOLLOY

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PREFACE

THE subject of sheet-metal work has in recent years become of first-class importance, owing to the advent of all-metal aircraft.

In addition to its use for wing coverings and fuselage skin, aluminium and aluminium alloys are used on practically all types of aircraft, for engine cowlings, fairings, and petrol tanks.

The use of sheet-metal in automobile construction has been standard practice for many years. In addition to these two very important applications, sheet-metal work plays a vital part in heating and ventilating engineering and a wide variety of engineering and allied trades.

This book presents an up-to-date survey of the processes and operations involved in the cutting and shaping of all types of sheet metal.

The first chapter describes the metals in general use, and their characteristics, and should prove a useful guide to the selection of the most suitable metal for any given job.

Before a start can be made on any but the most elementary articles in sheet metal, it is necessary to form a pattern. This ensures that the various pieces of sheet, making up the article, are cut to the correct shape, and so will fit together after the bending, folding, and forming operations. In Chapter II, full details are given as to this necessary process, so that anyone with no knowledge of geometry, when called upon to make up something, for the shop or job, can do so without wading through figures and formulæ in an endeavour to carry out the work in hand.

Chapter III deals with the actual cutting and forming work, using hand tools; while Chapters IV and V deal with the machines that can be used for forming sheet metal and describe how they are operated to get the best results.

Chapter VI, which describes the various methods of joining sheet metal, completes this section of the work.

The continued demand for this book has provided an early opportunity of revision. In preparing this revised edition a considerable amount of new material has been added on the welding of sheet metal by the oxy-acetylene process, by the arc welding process and by the process of resistance welding. Special points which must be taken into account in the welding of aluminium and copper sheet, and also alloys of either of these metals, are fully explained.

The final chapter deals with the method of shaping sheet metal known as metal spinning; it is believed that this chapter will supply much-needed information concerning a sheet-metal process on which very little information of a practical nature has hitherto been published.

E. M.

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SHEET-METAL WORK

Chapter 1

SHEET METALS IN GENERAL USE

SHEET-METAL work is generally regarded as the working of metal, from 16 gauge down to 30 gauge, with hand tools and simple machines into various forms by cutting, forming into shape, and joining. A brief survey of the metals in general use, together with their characteristics, will prove a useful guide for selecting the most suitable metal for any given job.

Black Iron

The cheapest sheet metal is black iron, which is sheet iron rolled to the desired thickness, annealed by placing in a furnace until red hot, and then set aside to cool gradually. This is known as open annealing, and the resultant sheet is covered with scale, owing to the formation of oxide on its surface, due to being heated in air. To prevent this scale from forming, a process known as "close annealing" is employed, where the sheets are packed in a box and sealed from the atmosphere and products of combustion during the annealing process.

Cold-rolled Close-annealed Sheet Iron

To still further improve the surface of the sheet it is run through polished cold rolls after annealing, and is then known as C.R.C.A. (cold rolled close annealed).

Common black iron is used where cost is the prime consideration, and when used for outside work it must be protected from the weather by painting or coating with boiled linseed oil.

C.R.C.A. may be used for all purposes where a sheet which is flat and possessing a good surface is required. It is an excellent base for paint or enamel, and is used for steel furniture, electric cookers, fires and refrigerators, air-duct and ventilating systems, bins, covers, hoods, and chutes, etc.

Silver Finish

A sheet of super-quality, descaled and cold rolled, known as "Silver Finish," has been developed, mainly for the motor trade, and is used

extensively for motor-body panels and wings. This is fairly malleable and ductile, easy to weld, and the smooth, scale-free surface is an excellent ground for the high finish associated with motor-body work. "Silver Finish" is the best grade of sheet iron manufactured, and can be used for the highest class of sheet-iron work, but its bright surface needs protecting with paint, enamel, or plating.

Blue-planished Steel

Blue-planished steel was formally known as Russian iron. It has a polished, gun-barrel-blue, oxidised surface, and is used where further surface treatment is undesirable, e.g. oven interiors. Great care is necessary in handling this metal, as, due to the fact that it is supplied covered with grease or oil to prevent damage in transit and storage by rust or scratching, the sheets are liable to slip through the hands and cause injury.

Tinplate

Tinplate is sheet iron coated with tin to protect it against rust. This is used for nearly all soldered work, as it is the easiest metal to join by soldering and, due to tin being the main constituent of tinman's solder, the solder alloys with the tin coating and makes a neat sound joint. Tin is a safe metal to use for culinary purposes, as food is not contaminated by contact. Common tinplates are rolled to the required thickness, annealed, immersed in an acid bath to remove the scale, dipped in flux, and then into a bath of molten tin which adheres to the surface. This first tinning leaves tiny pin holes and, while this is not detrimental for some classes of work, the better qualities receive a second dip in another bath of tin, at a lower temperature, which "floats over" the pin holes left in the first coating. The highest-quality sheets used for culinary and hotel work receive a third dipping in a tin bath, thus ensuring a heavy coating of pure tin on the surface of the iron. Great care is taken to preserve the surface of these sheets, and they are packed in boxes interleaved with tissue paper to prevent scratching in transit. The qualities of tinplates are known as Common, Best, and Best Best respectively.

The sizes and thickness of tinplates are denoted by special marks, not by gauge numbers, and can be very confusing to the uninitiated. It will be noticed that tinplate is only obtainable in fairly small sheets of light gauge. If larger or heavier sheets of tinned iron are required, the material used is known as Manchester plate or "tinned steel," and this may be obtained in all sizes and gauges in which sheet iron is obtainable. Manchester plate is a heavily coated sheet of the highest quality, and is much used for dairy utensils, hotel work, and petrol tanks.

Terne Plate or Lead-coated Iron

Lead would be an excellent metal with which to face iron sheets for protection, except for the fact that lead has little or no affinity for iron, and an addition of tin must be made to get it to "take." In most cases the tin content is low, but for soldered work a terne plate may be used, which is virtually a solder-coated sheet. This is much used for outside work which is to be joined by soldering, such as electric box signs.



MATERIAL BEING SHAPED IN LARGE BENDING MACHINE
(By courtesy of Tecalemit, Ltd.)

Galvanised Iron

Zinc is a metal which withstands contact with water and exposure to weather, but the poor mechanical properties render it unsuitable for many jobs requiring the characteristics of zinc combined with the high mechanical properties of iron. Zinc-coated iron is known as "galvanised iron," but the coating is not electrically deposited, as its name would suggest; but the sheet is dipped in molten zinc after being pickled, scoured, and fluxed with sal-ammoniac, the process being the same as used in the manufacture of tinplate. Galvanised tanks and other jobbing work is usually made in C.R.C.A. and galvanised after completion. Thus the zinc seals the joints and coats the edges, which if made of galvanised sheet would be bare iron and liable to rusting.

Aluminium

Due to the development of the aircraft and motor industries, aluminium has become the most important and widely used of the non-ferrous metals. Its lightness (specific gravity 2.56) makes it especially useful for aircraft parts liable to very little mechanical strain, the tensile strength being only about 9 tons per square inch. This is very malleable and

capable of being worked into most shapes without annealing. The metal "work hardens," and if the job has to undergo much stretching, it is advisable to anneal when the material becomes hard, to prevent the development of splits and cracks. Aluminium is used on aircraft mainly for engine cowling, fairings, and petrol tanks.

The panels on high-class motor bodies are made from aluminium for several reasons. Firstly, to lighten the body in order to give the high "power to weight" ratio necessary for good performance. Secondly, for ease of working and good surface finish; and thirdly, because, when scoured with a wire brush, a good base is formed for the heavy cellulose coating which is able to hold tenaciously to the scoured surface. As aluminium is rustless it is also durable, and the stripping of paintwork, owing to rust forming underneath, is obviated.

Aluminium cannot be soldered by ordinary methods, as the film of oxide which forms on the metal is tough and tenacious and cannot be broken down with soldering fluxes at ordinary temperatures. Welding and riveting are the methods used to join together aluminium parts.

Duralumin

This metal is used almost exclusively for aircraft work, for the fabrication of engine cowlings, fairing, fuselage skin, and tanks, and is a light alloy of high tensile strength (about 18 tons per square inch), and somewhat hard and brittle. For this reason, Dural should be annealed before bending or shaping is undertaken, and, as the metal "age hardens" rapidly, annealing should be carried out at least every two hours, and more frequently if the work entails hammering and stretching, otherwise cracks and splits will appear and the work will be ruined.

Dural cannot be joined by oxy-acetylene welding, and for this reason riveting is the most generally used method for jointing parts. It is now possible to join Dural by spot welding with a specially designed electric spot welder capable of producing the heavy current flow combined with the great mechanical pressure which is necessary.

The surface of Dural is very liable to corrosion, and so after the parts are made and normalised, they are subjected to anodic treatment in order to preserve the metal. Dural sheets are sometimes faced with aluminium, thus rendering anodic treatment unnecessary. Aluminium-coated Dural is known as "Alclad" sheet, and the method of working is the same as for Dural.

Copper

The characteristics of copper are its high conductivity of both heat and electricity, its red colour, which is capable of taking a high finish, and its remarkable ductility and malleability. This high conductivity

makes the metal especially suitable for hotel and culinary work, but as copper is dangerous when in contact with food, the surface which is liable to contact is coated with pure tin. Articles which are to be plated are frequently made from copper, as this takes a high finish, and is an excellent base for the deposition of plated metals (nickel, chromium, silver, etc.).

Copper can be joined by welding, but a special type of de-oxidised metal must be used.

Brass and Nickel Silver

Brass is an alloy of copper and zinc, possessing good working characteristics, and is used as a base for plated goods. Nickel silver, or German silver, is an alloy of copper (2 parts), zinc (1 part), nickel (1 part), making a white metal of excellent working characteristics. This is sometimes used in the natural state, as a white metal, but is more generally used for the highest class of silver-plated work.

Zinc

This metal withstands the weather very well, and is used extensively for outside work, such as roof work, gutters, spouts, etc. Care must be exercised when working zinc, as it is short grained (i.e. more granular than fibrous). Zinc is malleable at a temperature just hot enough to be comfortably handled, but is decidedly brittle at low temperatures. Owing to the poor working characteristics, this metal is more generally used as a coating for iron, in the form of galvanised iron.

Stainless Steel

This is an alloy of steel with nickel, chromium, and traces of other metals. In the original form (Staybrite) a fairly high percentage of carbon was present, which made it hard and difficult to work, but at the present time about fifteen grades of stainless steel are manufactured, with characteristics varying between high carbon content (suitable for cutlery and other tools) and a form which is virtually a stainless iron and which is as malleable as mild steel. Some stainless steels are unsuitable for welding, whilst others can be satisfactorily joined by this method.

Elektron

This is a light alloy with a high magnesium content, which is coming into prominence for aircraft work. Great care must be exercised in its working and handling, as when in small quantities (filings, turnings, cuttings, etc.) it ignites very easily and burns with a brilliant white flame which can only be extinguished by damping with cast-iron dust, sand, or special extinguishers.

Air Ministry Specifications

All metal used for aircraft work must conform to an Air Ministry Specification and be tested and inspected before being issued for aircraft work. To make identification easier the sheets are "Colour Marked," according to the specification, by dabs of paint in the corner of the sheet carrying the inspection stamps.

SPECIFICATION AND COLOUR MARKING OF SHEET
METALS USED FOR AIRCRAFT WORK

<i>Specification</i>	<i>Metal</i>	<i>Colour Band</i>
2.B.16 .	Brass sheet, half hard, for tanks	Red
3.L.3 .	Dural sheet	Yellow
2.L.4 .	Aluminium sheet, hard	Green
2.L.16 .	Aluminium sheet, half hard	Blue
D.T.D.111 .	Alclad sheet	Yellow and blue
2.S.3 .	Mild steel sheet	Green
3.S.20 .	Tinned steel for tanks	Black and green
D.T.D.171.A	Stainless steel for welding	Red and black

Chapter II

HOW TO FORM PATTERNS FOR SHEET-METAL ARTICLES

BEFORE starting on any project in sheet metal, a pattern should be developed to ensure the accuracy of the finished article. When a box, cone, pipe, or other shape is being made up, one of the illustrations given in this chapter will serve as a guide to procedure. In order to make the worked-out sketches as free from extraneous lines as possible, allowance for joints is not given. For repetition work, a pattern is developed and cut out from metal; the metal pattern is then used as a template from which the actual job is marked off.

Ninety-degree Angle Elbow (Fig. 1)

Nearly all patterns are made up from the development of a 90° angle elbow by full-size drawings of either an elevation or plan sketch. Having made the sketch with accuracy, it is necessary to draw a base line across the sketch as in Fig. 1. The line need not be in the position shown in this example, but immediately under the lower point of the elbow, if so wished. When this is done, make sure the developed pattern will be covered by the space allotted, otherwise it will be necessary to start the pattern drawing all over again. The allowance of margin therefore not only assists in time-saving, but acts in such a manner as to prove to the operator if his parallel lines are correct or not.

With the point of the dividers on the junction of the base line and the centre line, draw a semicircle on the base line equal in diameter to the sketch of the pipe. The semicircle is then divided into six parts without altering the dividers by using points 0, 3, and 6 as centres. Mark the sections off as shown in Fig. 1. It will be seen that this semicircle represents half the circumference of the actual pipe when finished. As both views of the pipe are the same it is not necessary to portray the side of the pipe not seen in our illustration, nor is it necessary to outline the other pipe, as the pattern will be exactly the same. The figured points 0 to 6 will represent six equal spaces around half the circumference of the finished pipe, there being no necessity to draw the other half, as the outline is the same. On the other hand, it will be neces-

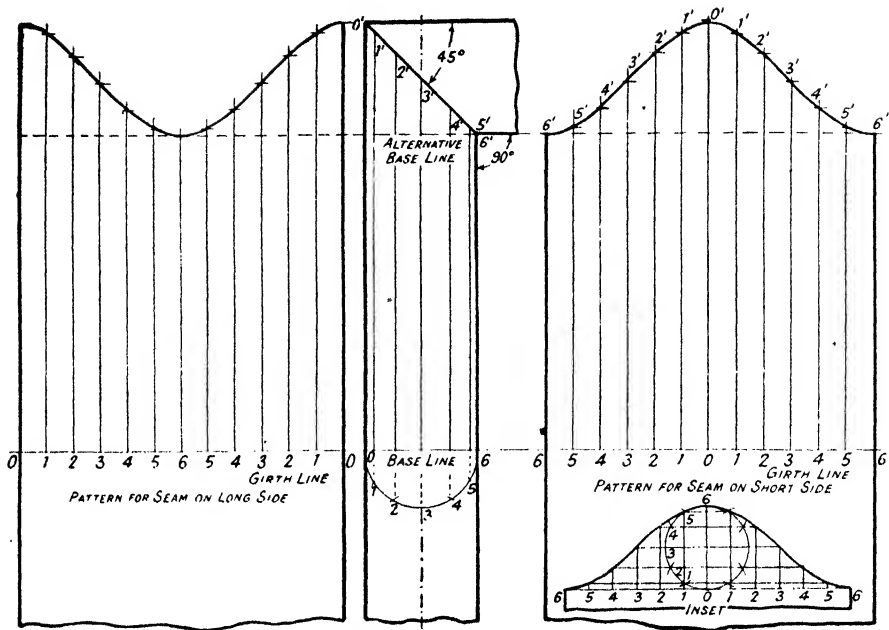


Fig. 1.—PATTERN FOR 90° ANGLE ELBOW

sary to mark out the unseen side of the pipe ; therefore, as one side of the pipe is the same as the other, the figures can be repeated. On the sketch of the pipe elevation, then, draw lines from the semicircle sections to the joint line at the elbow, and where these lines meet the joint, they will mark the places on the developed pattern where the sheet of metal will have to be cut to shape. As the sections on the semicircle equal twelve spaces around the actual pipe, it will be necessary to draw twelve parallel lines on the pattern, the distance between them being equal to any one of the sections on the semicircle, and *not the base line*. In this instance the base line is there to enable the operator to measure distances from the base line itself to the joint line. In our illustration two patterns have been given showing the difference in the patterns when the seam of the pipe is on different sides. At right angles to the parallel lines the base line is drawn and numbered as shown. Set the dividers to the distance 0 to 0' (base line to top of joint line) and with one point of the dividers on the mark 0 on the girth line of the pattern scribe the length 0' on the pattern itself. Scribe out lengths with the other numbers.

The illustration shows the scribings that will be made on the sheet and now it will only be necessary to freely connect up the marked point to form the correct shape of the joint.

No allowance has been made for jointing, therefore the difference will have to be drawn in before the sheet is cut. In the case of welding there will be no necessity to add anything to the pattern in any way.

It is assumed that both pipes will have the seams on the short side ; therefore the patterns will be the same. This is not absolutely necessary and the practised operator can draw both layouts on the same sheet, but in this instance the patterns are shown separately to enable the reader to clearly understand the method.

Another Method

There is another simple method for marking out a 90° elbow, but it applies *only to a right-angled elbow*. The first method has been given to show the principle on which all cylindrical sheets are marked out, whereas the inset in Fig. 1 pertains to no other layout. A circle equal in diameter to the pipe is divided into twelve equal parts, the girth line 6-6 being divided up in a like manner. The points to form the curve are obtained by running the construction lines up and across as shown in the inset.

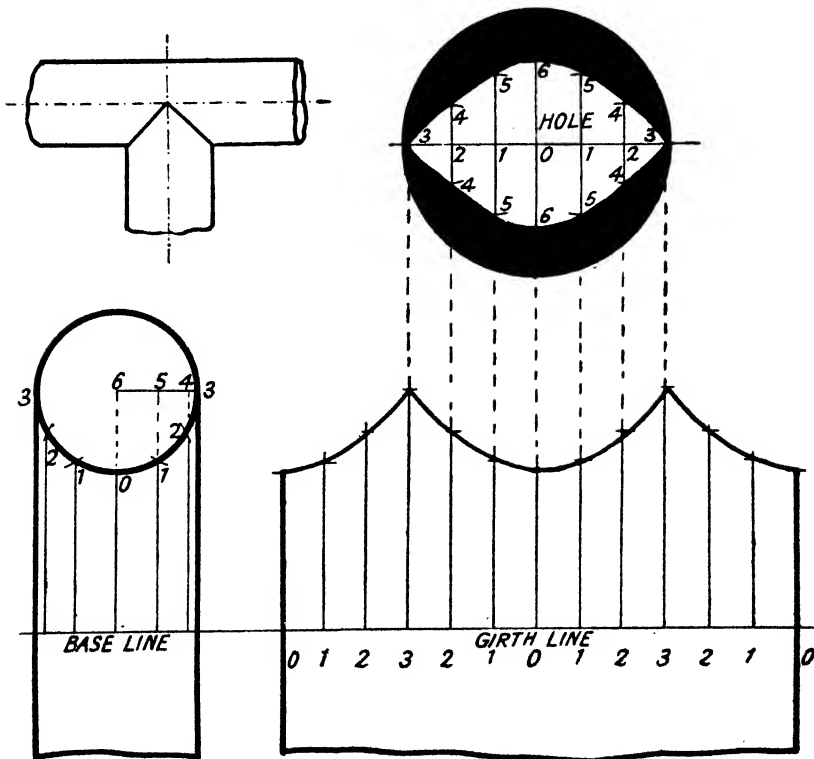


Fig. 2.—PATTERN FOR TEE-PIECE WITH BOTH PIPES THE SAME DIAMETER

Ninety-degree Tee with both Pipes the Same Diameter (Fig. 2)

This is a fairly straightforward job, but although it looks a little more complicated (Fig. 2) it is carried out by the use of only half the number of figures on the semicircle as the previous layout. The reason is that only a quarter of our circle is needed to produce the correct profile of the joint on the down pipe. One-quarter of the circle is divided into three equal parts without altering the legs of the dividers which were set to the radius of the pipe. In this instance 0 starts from the centre line, as this is the most suitable line for the seam, and twelve spaces marked off equal to 0-1, or 1-2, or 2-3, all being equal in dimensions. Lines at right angles are run up from the twelve places, and along them are measured the distances from the base line to the outline of the pipe from which our pipe branches. It will be noted that all lines from the base line bearing the same number are the same length.

Forming the Hole

On the flat sheet that will eventually form the joining pipe draw a line 3-3. This line is the girth line on the pipe, and *not a centre line*. Along this line space out 0-1, 1-2, and 2-3, all equal and obtained from the distance apart of these numbers on the circle. Set the dividers to 0-6 on the elevation and mark off 0-6 on both sides of a line drawn at right angles through 0 on the girth line. Similar lines having been drawn from 1 and 2 respectively, they also are marked off 1-5 and 2-4 each side of the girth line, thus giving the correct shape of the hole that will have to be cut in the sheet before it is rolled into a pipe. The hole has been set above the branch pipe pattern so that the reader can, graphically, obtain some idea as to how the actual hole shape is formed.

Ninety-degree Tee running into Larger Pipe (Fig. 3)

The patterns in this instance (Fig. 3) are different from the previous tee piece, in that the larger diameter of the main pipe flattens out the developed curve on the smaller branch pipe. The spacing on the girth line of the larger pipe is also produced in a different manner, owing to the sections marked off on the semicircle imposed upon the base line of the smaller pipe being smaller than similar sections would produce if the larger pipe was similarly treated. In this instance the spacing on the girth line *E F G H G F E* is set out with *H* in the centre and spaced *H* to *G*, *G* to *F*, and *F* to *E* on either side of *H* on the circle denoting the larger pipe. The *lengths* of these lines will be marked from the base line to the periphery of the base circle of the smaller pipe, viz. *D* to *L* on *H*, *C* to *K* on *G*, *B* to *J* on *F*, and the point *E* will be on the same spot as *A* on the girth line.

Letters have been used to denote the various spots, as figures rising above the value of 10 would be somewhat confusing, but it must be remembered that the practised mechanic seldom uses any characters to

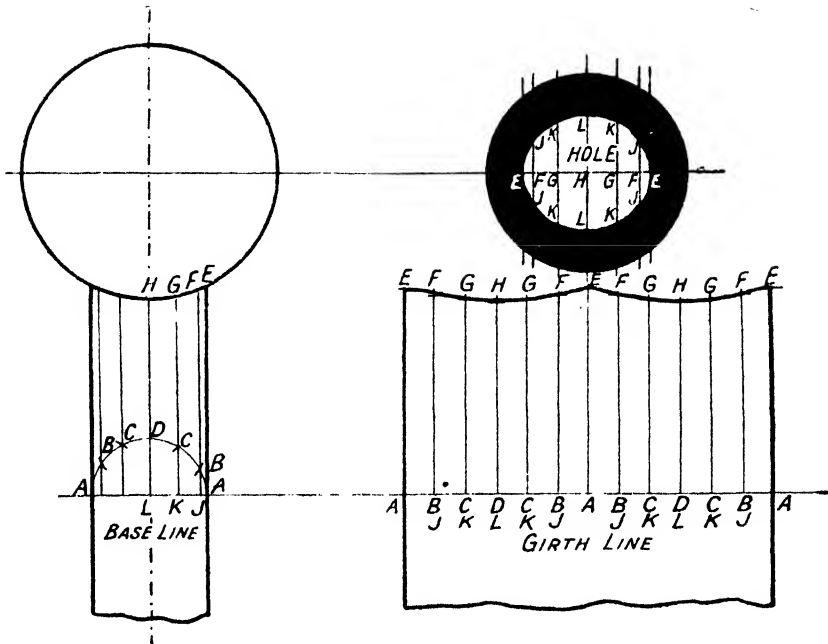


Fig. 3.— PATTERN FOR TEE-PIECE WITH PIPES OF DIFFERENT DIAMETERS

denote the various points, carrying the names or figures and letters of the points in his memory. In any description it is necessary to use some form of figures and lettering as an explanation of the method of procedure.

The marking out of the down pipe is on the same principle as the preceding examples and is *L* to *H* on lines *D*, *K* to *G* on lines *C*, *J* to *F* on lines *B*, and *A* to *E* on lines *A*. In the example shown the seam is at *A*, but it can be arranged at *D*, if thought necessary, by fixing *A* at the point now allotted to *D* and sketching out the pattern accordingly.

Thirty-degree Branch Pipe, both Pipes the Same Size (Fig. 4)

The principle of marking out the patterns remains the same, although there is a slight variation (Fig. 4). On both patterns all figures have been left out on the cutting lines, but dotted lines showing how the various points are produced have been drawn in. It will be noted, however, that only a quarter segment of the semicircle formed on the base line of the vertical pipe has been used to obtain the points for cutting out the hole, although the semicircle itself has been figured to show the circumference of the pipe and the position of the hole. The joint between the two pipes has been drawn in, although the position was not known until the parallel lines drawn on each pipe met and denoted where the joint should be. On the branch pipe it will be noted that line 1 on the pipe elevation

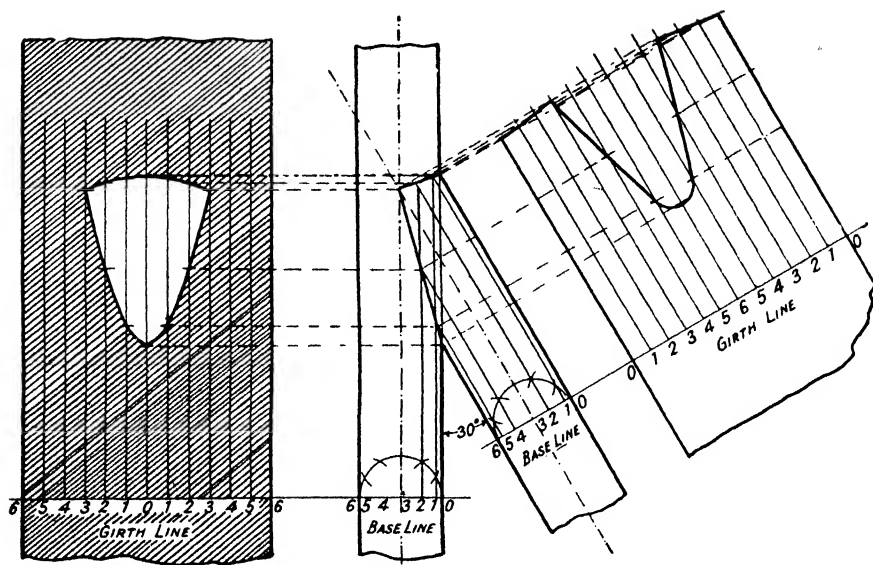


Fig. 4.—PATTERN FOR 30° BRANCH PIPE, BOTH PIPES BEING THE SAME SIZE

intersects line 1 on the pattern of the same pipe ; exactly the same takes place with other figures of the same denomination.

Regarding the figuring on the other pattern, it will be noted that 0 intersects 0 on the pattern, 1 intersects 1, 2 intersects 2, 3 intersects 3, 4 intersects line 2 on the pattern again, 5 again intersects 1, and 6 again intersects 0, thus producing the correct shaped hole in the vertical pipe.

Right-angled Small Offset Tee (Fig. 5)

The pattern of the small pipe (Fig. 5) is laid out by dividing into twelve equal parts measured on the semicircle built upon the base line of the smaller pipe. Marked off at lengths 0-0, 1-A, 2-B, 3-C, 4-D, 5-E, and 6-F from the small-pipe base line and *not from the sections on the semicircle*, the small-pipe pattern shape, where it meets the large pipe, is illustrated with its peculiar form specially on the line 6. This is owing to the smaller pipe being just a little larger than half the diameter of the large pipe. The figure has been specially produced to give an idea of the shape, although not likely in actual practice. The girth line of the large pipe is laid out, and at distances along it are scribed off measurements 0-A, A-B, B-C, D-E, and E-F, obtained from the circle denoting the larger pipe. Lines at right angles are drawn through these points and their length determined from the small pipe base line to 1, base line to 2, base line to 3, and so on. As 1 is the other end of A, the dividers' point is placed at A on the girth line and the point 1 marked off on either side. The cutting line of the hole is freely drawn in.

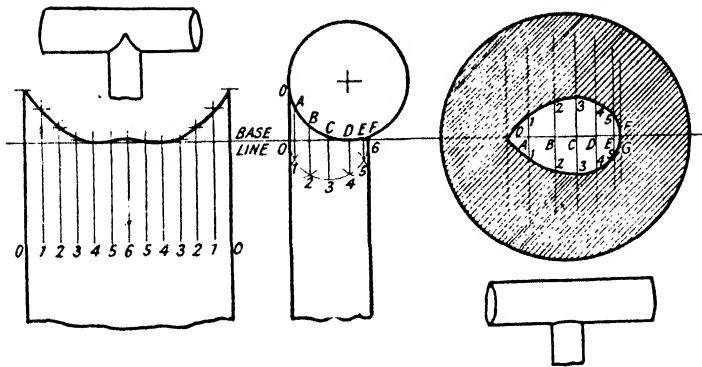


Fig. 5.—PATTERN FOR RIGHT-ANGLED SMALL OFFSET TEE

Forty-five Degree Small to Larger Offset Pipe (Fig. 6)

This layout (Fig. 6) is a little more complicated than those already explained. In this instance the small pipe has the usual base line and its imposed semicircle, but it has been found necessary to number both sides of the semicircle, as the obverse side of the branch pipe takes up another shape to that shown on the front. It has also been necessary to produce a similar base on the top of the large pipe. In perspective this semicircle would be at right angles to the lower semicircle and has been drawn to locate the position of the joint on the large pipe. From the point of view of the lines drawn along the small pipe, the position of the lines remain constant, but those on the other side are of different lengths. Observation of the sketch will show that the lines drawn through 0, 1, 2, 3, 4, 5, and 6 meet the same numbered lines drawn from the base at the top of the large pipe. Where these lines intersect will be the joint line on the seen side of the pipe, but where lines 7, 8, 9, 10, and 11 intersect the similarly numbered lines (dotted for ease in viewing) on the large pipe will be formed the joint on the unseen side. The unseen joint line is also dotted. The circle equal in diameter to the large pipe has been drawn to locate the small base pipe lines in their correct position. The pattern of the small pipe is numbered from 0 to 11 and again 0 (0 being the same spot as the 0 on the other side of the drawn pattern). Lines drawn at right angles to the side of the small pipe will intersect the vertical (and parallel) lines drawn upwards from the small pipe base and spaced equal to the sections of the semicircle. Number 0, where the two pipes meet, will intersect lines 0-0 on the pattern, also where lines 3 intersect on the elevation is the point from which a line will be drawn to line 3 on the small pipe pattern, and so on from all the other intersections.

The shape of the hole is obtained by constructing the line *A-B* from the point *A* at right angles to the large pipe. At right angles to the line *A-B* draw the line 0. Measure off 0-1 on the large pipe circle and space

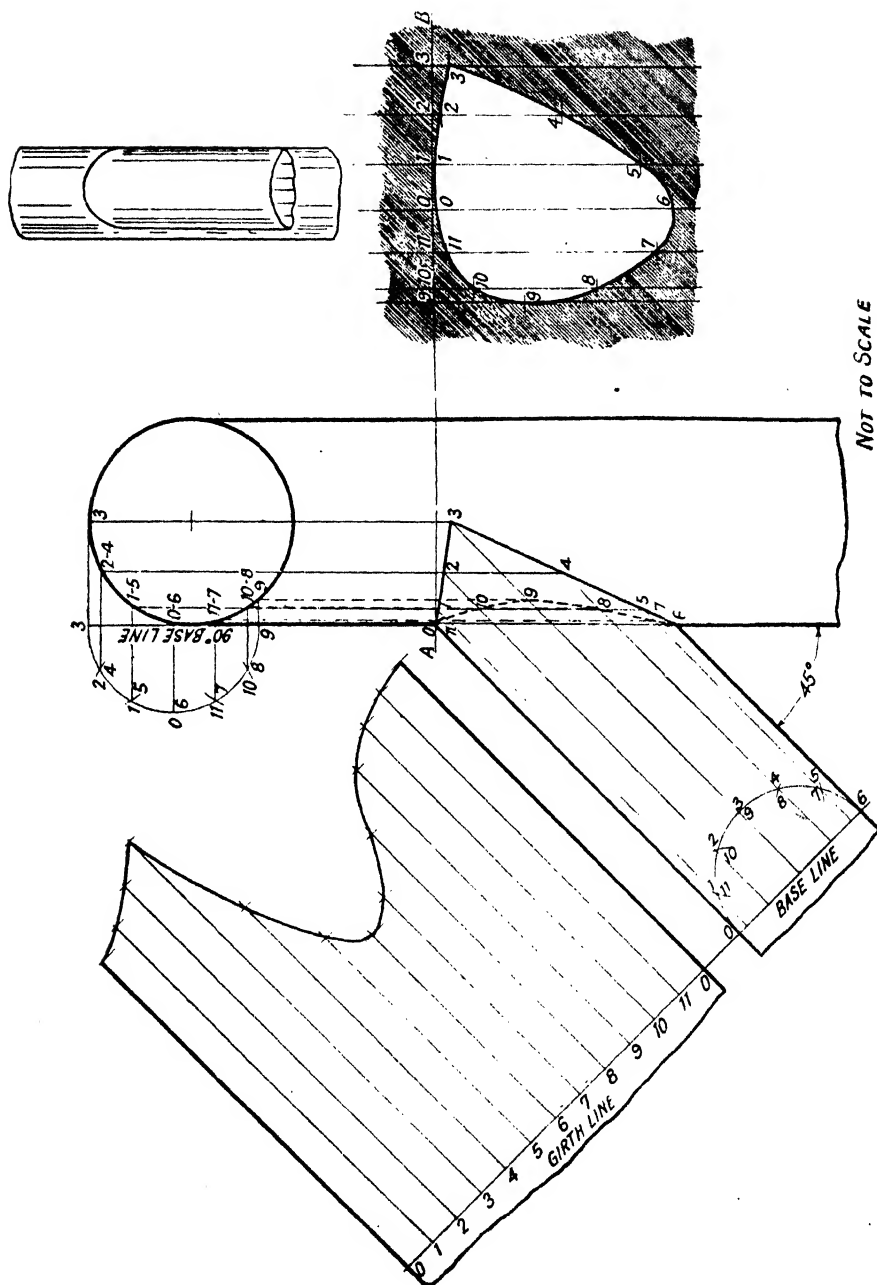


Fig. 6.—PATTERN FOR 45° SMALL TO LARGER OFFSET PIPE

0-1 on the line *A-B*. Then 1-2 and 2-3. On the other side of line 0 mark off 0-11, 11-10, and 10-9, not forgetting that these measurements are obtained from the large circle where the extended lines from the base semicircle are imposed on it.

There is nothing mysterious in the short straight lines from the top base line to the periphery of the large circle. The position selected for this base line is the most suitable, and the straight lines simply convey the true value of the measurements set out on the semicircle. The same arrangement is met with from time to time in such work.

The other measurements pertaining to the hole should need no explanation, excepting that the markings are parallel continuations of the various intersecting points on the elevation.

Forty-five Degree Small to Large Pipe on Centre Line (Fig. 7)

In view of the fact that a more difficult branch has been described in the last section, it is not necessary to go into many details with this form of joint (Fig. 7). The base line on the branch is numbered as usual and the semicircle sections spaced along the girth line of the pipe itself. From the quarter circle imposed on the large pipe, numbered on both sides, show that both the sides seen and unseen on the elevation are alike, therefore there is no necessity to increase the number of points. The actual joint line has been left out for a better view of the intersections and the conveyance of the cross-lines to the layout for the hole in the other pipe.

Mention of the fact that the pipe circumference is the diameter $\times 3.1416$ should warn the operator that patterns should be checked against a rule before any cutting is carried out. The slightest error on sectioning the semicircles will be multiplied by twelve in the layout of the pattern. The difference in method of laying out the 90° base line to that shown in Fig. 6 has been done purposely to show the alternative when it suits the case. A little study of the situation will prove there is no difference whatever as to the result.

Pipe Bends (Fig. 8)

It is impossible to draw the actual pipe bend until one has laid out certain measurements of both the length and the offset of the bend itself. Fig. 8 shows the bend, but it has been produced from the layout of the inset in the left-hand corner.

Let the parallel lines *A* and *B* form the beginning and the finish of the desired bend, and the lines *C* and *D*, both at right angles to *A* and *B*, form the centre lines of the straight pipes, therefore the offset of the bend. The lines *A*, *B*, *C*, and *D* form a rectangle; therefore from the corners in the same direction as the bend draw the line *G*. The line *G* is then divided into four equal parts as shown in inset. It is easily carried out with the dividers by creating the point *G* first. From point *G* and the

corner in direct line the dividers should be set to a little over the half-way mark and so provide a guide to lay out the lines $X-E$ and $X-F$, which are at right angles to the line G . By using the dividers as stated there is no necessity to use a set-square. Carry on the lines $X-E$ and $X-F$ until they intersect respectively the lines B and A .

The points E and F will be found to form the true centres of the bend. The bend should now be formed into an equal number of sections (eight in this instance). A centre line should be drawn through one of the equal sections and upon this should be built up the usual semicircle showing half the circumference of the section. The semicircle is divided into six equal parts and numbered 0, 1, 2, 3, 4, 5, and 6. Vertical lines from the centre line are drawn to meet the numbered points on the semicircle. With one point of the dividers on point F they are set to the verticals on the centre line and radii produced to meet the joint line of the section. 0 and 6 remain constant, but the radial lines are numbered 1', 2', 3', 4', and 5', respectively. The patterns are laid out in the ordinary manner in twelve parts equally spaced from the sections on the circumference of the semicircle and *not the centre line which has formed the base line*. From the point of uniformity the seam should remain on the same side, therefore two patterns are shown needing sections of four each to be made up.

From this same layout it must not be thought that a right-angled bend can be produced owing to the lines $A-B$ and $C-D$ not being equidistant. A right-angled bend is shown in the inset of Fig. 8. The bend can have any number of sections, providing they are all equal in size; therefore there is no necessity for the joint line of a section to come on the 45° line of the layout. In the inset the number of sections happens to be six, but the number could be five or seven, according to material and size of the pipe, and this applies to all bends.

Cones (Fig. 9)

Plain cones, if small, are easily developed by sketching out a half-elevation and graphically working out the pattern, but this is not always possible; therefore the formula is herewith given and illustrated in Fig. 9. Invariably the diameter of the base and the height are known, but if any two sides are at hand, the length of the third side can be obtained by arithmetic. The formula is based on the solution of right-angled triangles, and, as half the elevation of a cone is bound to form a right-angled triangle, the formula given in Fig. 9 is of service. This formula does not apply to triangles without one of the angles being 90° . In our illustration the "slant length" is side A , the height of the cone side B , and half the base line forms side C . Our cone has a height of 10 in. (B) and half the base diameter is 15 in. (C); therefore the sum resolves itself into $\sqrt{10^2 + 15^2}$ and equals $\sqrt{100 + 225}$ and results in the slant length being 18.0278 in.

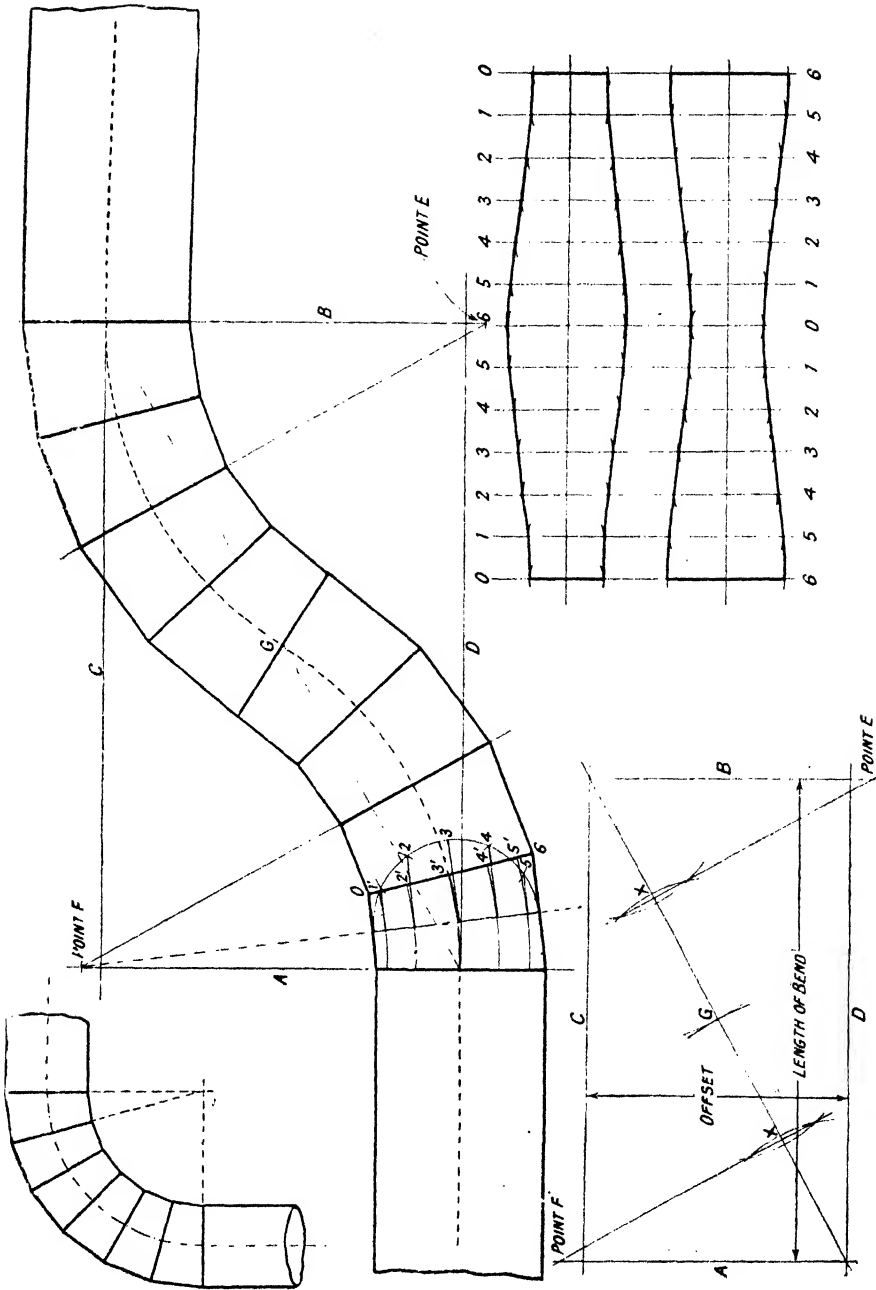


Fig. 8.—PATTERN FOR PIPE BEND IN SEGMENTS

In arriving at the amount of the gap to be cut out of the pattern it is sometimes advisable to calculate the sum of the gap itself instead of the length of arc. If that is so, the following is the formula :

(Slant length $\times 2$) — (Half the base diameter $\times 2$) $\times 3.1416$.
This equals—

$$(18.0278 \times 2) - (15 \times 2) \times 3.1416 = (36.0556 - 30) \times 3.1416 = 19.02427$$

(approximately $19\frac{1}{32}$ in.) to be discarded from the pattern.

Another method in degrees :

$$\frac{360^\circ \times \text{half base length}}{\text{slant length}} = \frac{360 \times 15}{18.0278} = 299.5^\circ$$

length of arc, or 60.5° the length of gap to be cut from the arc. Graphically the length of radius of the arc is obtained by placing one point on the centre line where the slant length touches and opening the dividers to the length of slant and constructing a circle. On the complete base line of 30 in. a semicircle is drawn and a half of this again divided into three. Twelve of the sections are then spaced off around the circle on the pattern and should produce the point from where a line is drawn to the centre of the circle of the pattern and form the section to be cut away from the pattern.

All measurements should be checked with a steel tape or piece of wire.

Conical Elbow on Parallel Pipe (Fig. 10)

In this example of sheet-metal work (Fig. 10) we have added another rule to those in the preceding pages. The new procedure is to draw the elevation of the vertical pipe and construct at the end a circle of the same diameter as the pipe. This is absolutely necessary, as the lines forming the side of the cone must touch the circle in the same manner as the parallel lines of the pipe. Unless this is arranged, the cone, where cut to

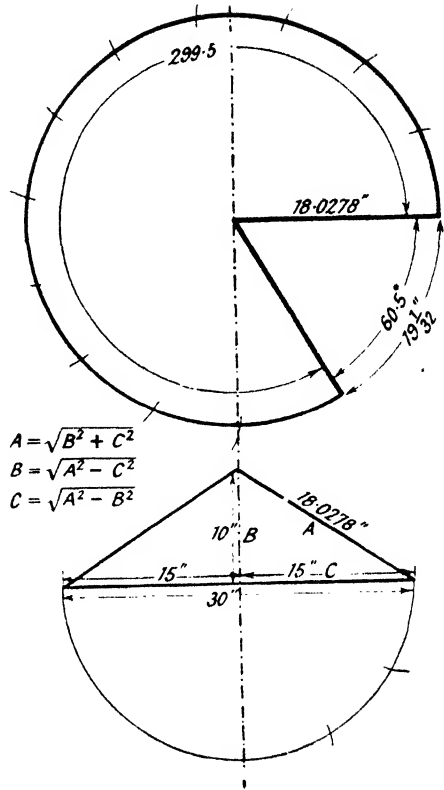


Fig. 9.—PATTERN AND FORMULÆ FOR CONE

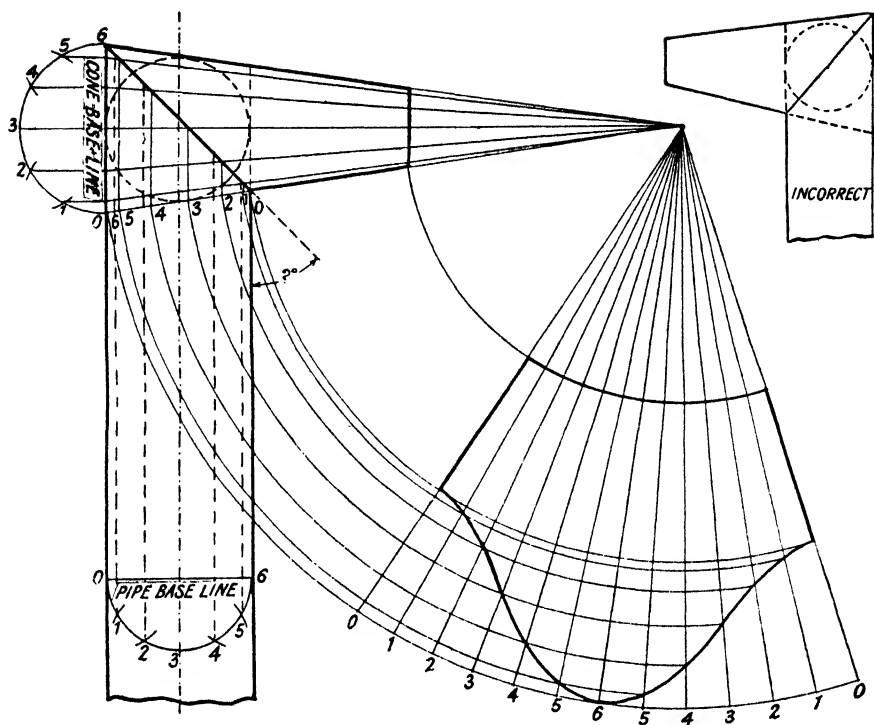


Fig. 10.—PATTERN FOR CONICAL ELBOW ON PARALLEL PIPE

form the joint, will be a different dimensioned ellipse to the ellipse formed on the parallel pipe where it is cut to form the joint.

An inset to Fig. 10 shows an incorrect layout where the dotted circle only touches one pipe instead of both. It will be noticed that the cone pipe is produced right through to the outer edge of the vertical pipe, not only to prove that it touches the circle as already explained, but to show the true value of the cone base. Upon this base is produced the usual sectioned semicircle with its lines drawn at right angles to the cone base. From this line it will be noticed that the lines are then drawn to meet at the apex of the cone, but where they reach the joint line (the position of which we knew when the elevation was drawn) they are then deflected parallel to the base line until they reach the surface of the cone. From these points lines are drawn with the apex of the cone as a centre, whilst the intersecting lines are, as usual, spaced from the sections on the cone-base semicircle.

Be sure this spacing is marked off on the line *O*, otherwise the dimensions of the divisions will not be the correct size. It will be seen that the angle is marked ($?^{\circ}$). This has been done so that the angle should not be

taken for granted as a right angle, although very near it. It should also be observed that, owing to the cone, the joint line does not pass through the centre of the dotted circle, which it would do had the elbow been one of parallel pipes of equal diameters.

It is wise in all sheet-metal work to take nothing for granted, and this is an excellent example. The parallel pipe has a base line of its own and the lines drawn along the pipe are another proof that the lines differ for each pipe. The pattern of the parallel pipe is not shown, as examples of the development of the pattern have already been given.

Cone, Angled Top and Bottom (Fig. 11)

Fig. 11 looks somewhat complicated, but is really straightforward, whatever the angle of either cone or angles at the ends. The bottom of the cone elevation is extended until a base line at right angles to the centre line can be drawn and sectioned on the semicircle, as in other instances. From the base line 1, 2, 3, 4, 5, and the outside, lines are conveyed to the apex of the cone. On the edges the lines are diverted to the outside of the cone so that their true value can be conveyed by radial lines to the pattern. The radiating lines of the pattern, drawn from the cone apex, are equally spaced as the sections on the semicircle and *not the base line*. The spaces are marked out on the radial line 0, otherwise their value will be incorrect. At the small-angled end of the cone lines are again drawn parallel to the base line until they reach the side of the cone elevation, and from there, using the cone apex as a centre (X), they mark off the radiating

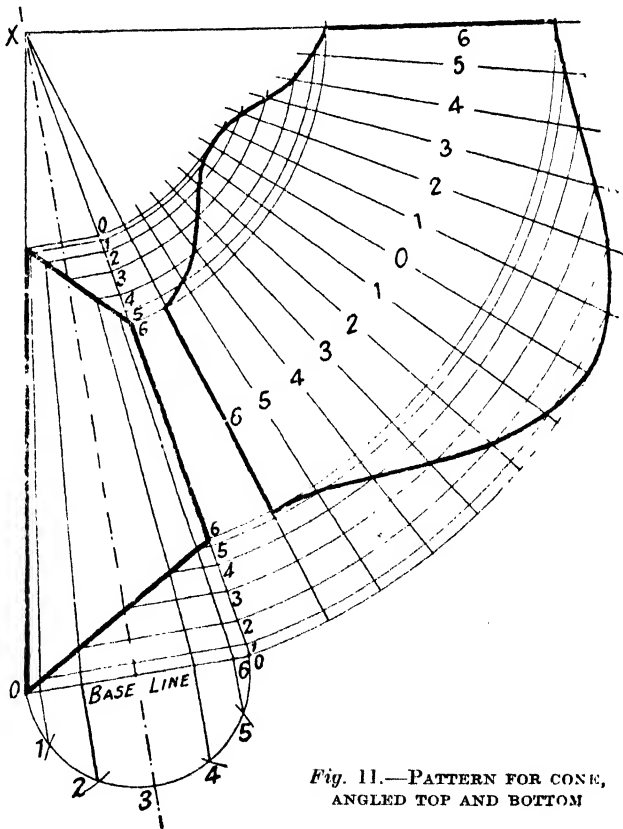


Fig. 11.—PATTERN FOR CONE, ANGLED TOP AND BOTTOM

lines at points of the same number, exactly as the ones at the other end of the cone. The larger end of the cone has been chosen on which to form the base line, on account of its larger size and the lesser possibility of error in consequence ; otherwise it makes no difference as to which end the base line is formed.

Large Cone with Two Others Imposed at Different Angles (Fig. 12)

Fig. 12 is an example of cone joints specially set out to explain the system, although not likely to happen in actual practice. However, it may be the lot of the operator to be called upon to make up something based upon the method of making such patterns, especially as the principles explained are used in everyday practice.

It will be noted that in laying out the design the dotted circle has had to be used before the imposed cones can be drawn in, also the joint lines are not known until the detailed sketch has been produced. Those parts of the cones not actually in the finished article have been dotted in so that it will be known where the joints will be located.

Having drawn in the three cones, run a pencil line from *A* to *C*, then another line from *B* to *D*, and from the point where these two lines intersect run a line to *E*. Thus will be formed the joints of the three cones. The unwanted parts of the lines *A-C* and *B-D* should be rubbed out to save confusion, as they may be mistaken for wanted lines.

The usual semicircle has been drawn on the base of the vertical cone, but with the two other cones the semicircles have been drawn on the smaller ends. This has been done so that the layout can be clearly seen. It may be thought that it is a change of principle to place the cone base semicircle on the other side of the cone base, but the inset shows that the result is the same. The right-angled lines drawn *from the sections* of the whole circle meet on the base line from whichever side they be drawn. For explanatory reasons the same apex points have been used for both the elevation and the respective patterns, although the radial connecting lines have been left out on account of the inability of sorting out the many lines in such a small space.

The reader should test out the elevations and their relationship with the patterns with dividers, when the layout will become clear.

It will be seen that on two of the elevations and patterns there are lines marked *X*. The reason these are in evidence is that neither of the lines 0 to 6 meet some of the essential points on the joint. On the vertical cone line 3 does not touch the highest point of the joint, and it is imperative that this point should be known ; therefore the extra line from this point to the base line is shown by laying a straightedge from point *X'* to the specially required point on the joint line, drawing in the necessary line to the cone base line. From here it runs at right angles to the periphery of the semicircle, thus giving its true position on the pattern. It is there spaced off from 3 towards 4 and marked with an *X*. The

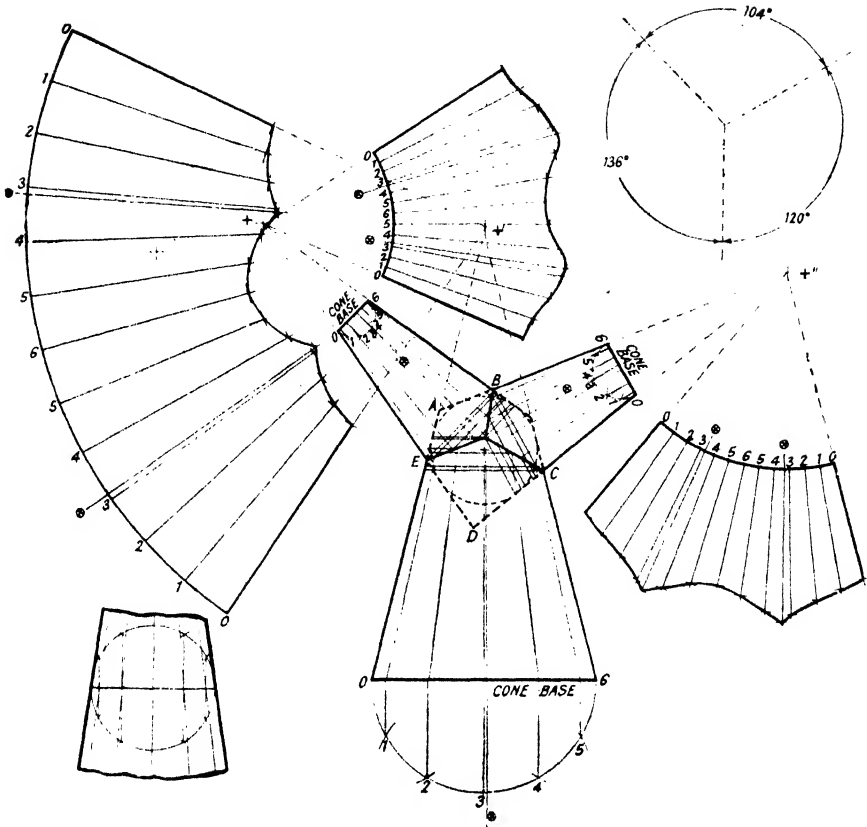


Fig. 12.—PATTERN FOR LARGE CONE WITH TWO OTHERS IMPOSED AT DIFFERENT ANGLES

points can be clearly seen on the pattern in their correct positions. It has been found necessary to use these special lines in all three cones.

It is good exercise for the mechanic to lay out such formations, not forgetting to base the designs on the use of the dotted circle, notwithstanding the fact that the centre of the circle is frequently well away from the joint common centre.

Conical Hopper Imposed on Slant Pipe (Fig. 13)

Fig. 13 shows that we have arrived at a further stage in the development of both pattern and shape of the hole to be cut in the slant pipe.

The usual semicircle showing half the circumference of the top of the hopper is drawn on the elevation and section, and then numbered. A base line semicircle is drawn at a suitable position on the slant pipe (it does not matter exactly where), but *not sectioned off*. The base line, which is,

of course, at right angles to the slant pipe, is extended and marked $A-B$ for reference. Lines are extended from the base line of the hopper, all joining at the apex of the hopper cone. Dotted lines are then drawn parallel to the slant pipe and pass right through the line $A-B$. The length of the dotted lines on the outer side of the line $A-B$ are determined by measuring the distance along the lines reaching from the periphery of the semicircle to the base line on the hopper. Thus the lines 1-1, 2-2, 3-3, 4-4, and 5-5 are transferred to the dotted 1-1, 2-2, and so on.

We now draw the line $C-D$ through the apex point E . This line is parallel to the slant pipe and passes through the line $A-B$ at right angles. Where $A-B$ and $C-D$ intersect, mark the point F . From the point F draw dotted lines to the extended dotted lines and join them where they have already been distanced off from the line $A-B$. The lines radiating from the point F will then pass through the semicircle drawn on the slant-pipe base line. At the points where they intersect the semicircle draw lines parallel to the slant pipe until they reach the lines drawn on the hopper of similar numbers. The points of intersection will form the joint between hopper and slant pipe.

Draw in the joint line, and then, parallel to the hopper base line, draw in from the intersections the lines leading to the extended edge of the hopper elevation. The usual twelve lines radiating from E will represent the circumference of the hopper, the spacing being *equal to the sections on the hopper semicircle*, and spaced out on radius 0, which will form the top edge of the hopper itself. The actual lines drawn by using E as a centre have been left out owing to the number of lines already in use. The line $X-X$ will be noticed drawn at right angles to the slant pipe and starting from the centre line (3) where it meets the slant pipe. It is on this line the details of the hole will be laid out.

From this line the dotted lines 1 and 2 have become full lines for the purpose of denoting on which side of the line $X-X$ they are. Note that 1 and 2 are on one side of $X-X$ and 3 in the centre, whilst 4, 5, and 6 are on the other side.

On the metal sheet that will form the slant pipe draw the girth line $X-X$, and across this line, but at right angles to it, draw line $G-G$. At the point of intersection place the figure 0 on one side and 6 on the other. With the dividers space off (from line $A-B$) the distance between 0 and 1 on the slant-pipe semicircle. Convey this distance to the line $X-X$ and mark off the space 0-1 on either side of 0. Convey the distance between 1 and 2 on the same semicircle and then 2 and 3. Remember that 6 and 0 are both on the same spot, both on the semicircle and on the line $X-X$; therefore repeat the process by spacing off 6 to 5 from the semicircle and transferring the distance to 6-5 on line $X-X$, the same with 5-4 and 4-3.

If you have made your drawing correctly, the repeated 3's should cover exactly the same spots on both ends of line $X-X$.

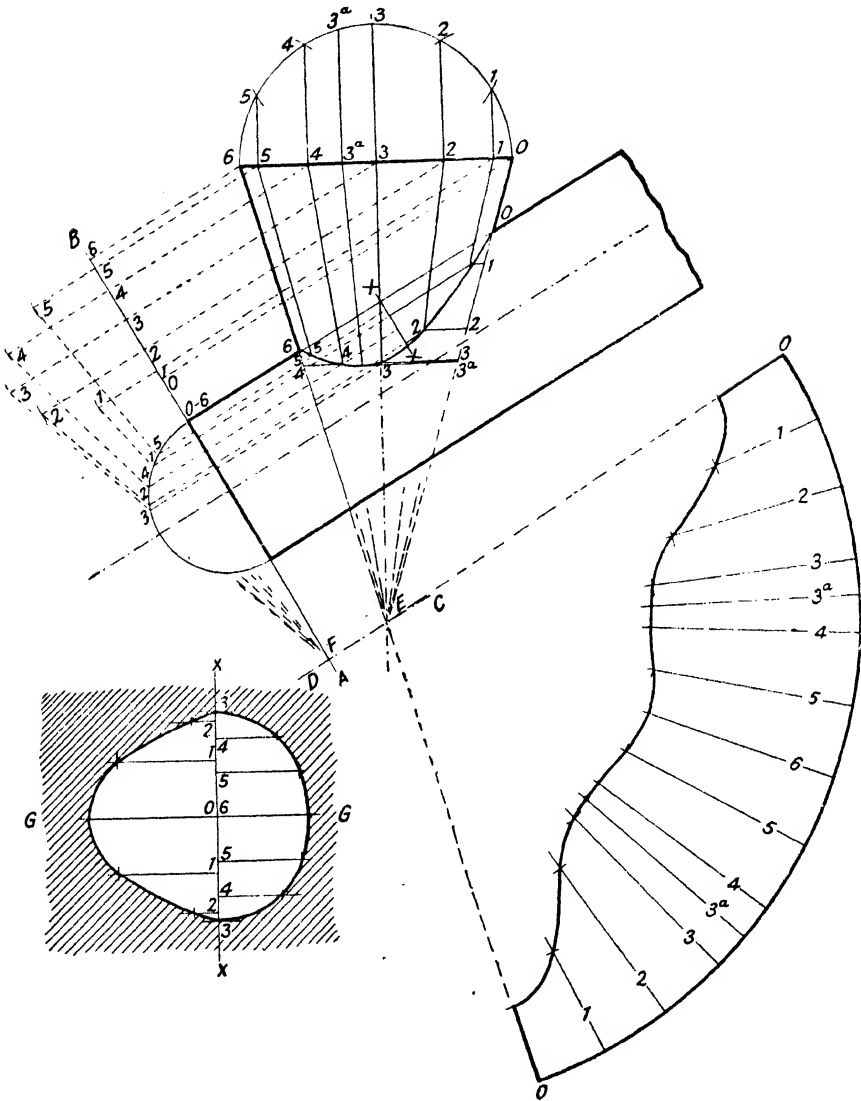


Fig. 13.—PATTERN FOR CONICAL HOPPER IMPOSED ON SLANT PIPE

On the hopper elevation, space off from the centre line $X-X$ the length 0 and mark off the line 0 the same distance on line $G-G$ from 0, then mark the distance from $X-X$ to 1 on the hopper elevation and transfer to line 1. Do the same with 2.

Give your attention to the other side of $X-X$ on both hopper and

girth line and mark off $X-X$ to 6 along $G-G$ from the point 6. Do the same with $X-X$ to 5, $X-X$ to 4. All the distances from $X-X$ are to the joint line and *not the extensions* to the edges of the hopper. A free line through the marked-off lines will give the shape of the hole in the slant pipe. The line 3a shown on the elevation of the hopper has been drawn, as explained in the previous chapter, to show the extreme length of the hopper joint line.

It has not been found necessary to extend this line to that portion dealing with the hole in the slant pipe, as the existing lines are quite adequate.

Development of Cone by "Long Method" (Fig. 14)

Some cones are of such very slight taper that, if any size at all, would take the whole floor of the workshop to lay out if the pattern were to be developed from the apex of the cone. For such work there is another method based upon triangulation. If three sides of a triangle are known, the triangle itself takes up a particular shape and one shape only. It is on this rule that the "long-measure" system is carried out.

In our example (Fig. 14) we have laid out the usual semicircles on the large base, and running up the dotted line $J-G$ we have been enabled to draw the semicircle of the smaller end of the cone on the same line. There is no reason why the second semicircle should not be built upon the bottom of the elevation, excepting that it is more convenient to place it on the top along with the other semicircle.

The semicircles are divided into six equal parts, numbered and lettered as shown. With one leg of the dividers on the point G and the other on the point 5, describe an arc finishing at H on the extended base line. The distance $J-H$ will give us the diagonal line with which to form our triangle and thus locate the correct positions of our points on the developed pattern.

The first thing to do in sketching out the pattern is to draw the line $0-A$, which line will be the same length as $0-A$ on the elevation. From the point 0 develop the arc $0-1$, and from A develop the arc $A-B$ obtained from their respective semicircles. Set the dividers to the length $J-H$ on the elevation and with one leg on the pattern at 0 scribe an arc meeting the radius of the distance B from A . Transfer the leg of the dividers to A and at the length $J-H$ describe another arc crossing the smaller one at 1, exactly as shown in Fig. 14.

If the operator has more than one set of dividers, it is as well to set one pair at the length $J-H$ and fasten them so that with the frequent measurements during the laying out of the pattern they cannot be altered. It is this long diagonal measurement that is so important in the correct development of the pattern. The same applies if you can set another pair of dividers to $0-1$, and another pair to $A-B$ on the periphery of the semicircles and lock them in position.

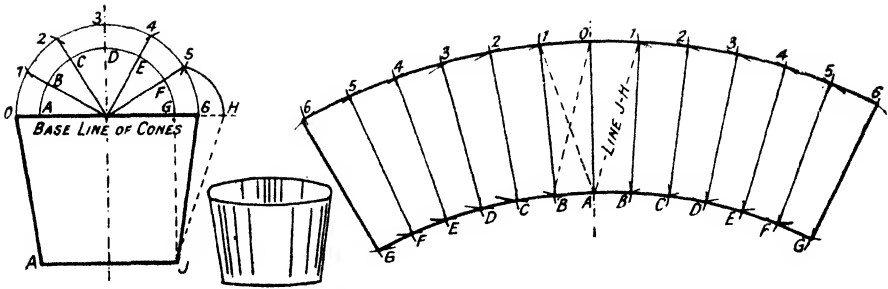


Fig. 14.—DEVELOPMENT OF CONE BY "LONG-MEASURE" SYSTEM

From the intersecting point 1 radius off $J-H$ again, likewise from B . From point 1 mark off the length equal to $0-1$ and on the intersection place the figure 2. From B mark off a distance equal to $A-B$ and mark off C , and so on until all the twelve sections have been marked out, not forgetting to locate the point positions with the aid of the diagonal line $J-H$ in every instance.

In actual practice it is not found necessary to draw lines, but only to mark off the various points, except in the case when the method is being used for the first time.

Square and Rounded Hoods (Fig. 15)

The square hood shown in the top of Fig. 15 presents little difficulty and is arithmetically worked out as mentioned in a previous paragraph; but the average mechanic, especially when it comes to "square roots," is not particularly happy. The side measurements of the hood layout are generally known because the hood has to cover a certain stove or hearth; therefore width and depth have first to be determined. It is the slope of the front that is mostly the unknown quantity. Without figures the 42 by 30 triangled side can be laid out to form one side of the pattern, and the part that will form the front portion is built upon it without in any way troubling about measurements at all. The line $W-W$ can then be drawn parallel to the bottom edge of the hood and, passing through the corner of the first side, so determine where the 90° angled corner comes in the third side.

The lower sketch elevation and the resulting pattern is that of a similar hood, but with large rounded outer corners. In the example given it has been assumed that from H to O is straight. At right angles to the sloping front draw a line passing through the back corner. On the bottom line of the hood, produce the quarter circle and divide into three equal parts. As the portion from H to O is straight, the radius of this quarter-circle will be $E-H$ with the centre at H . Draw lines from the periphery of the quarter-circle to meet the edge of the hood as shown. Prolong the lines parallel to the sloping front and measure off $3'-F$.

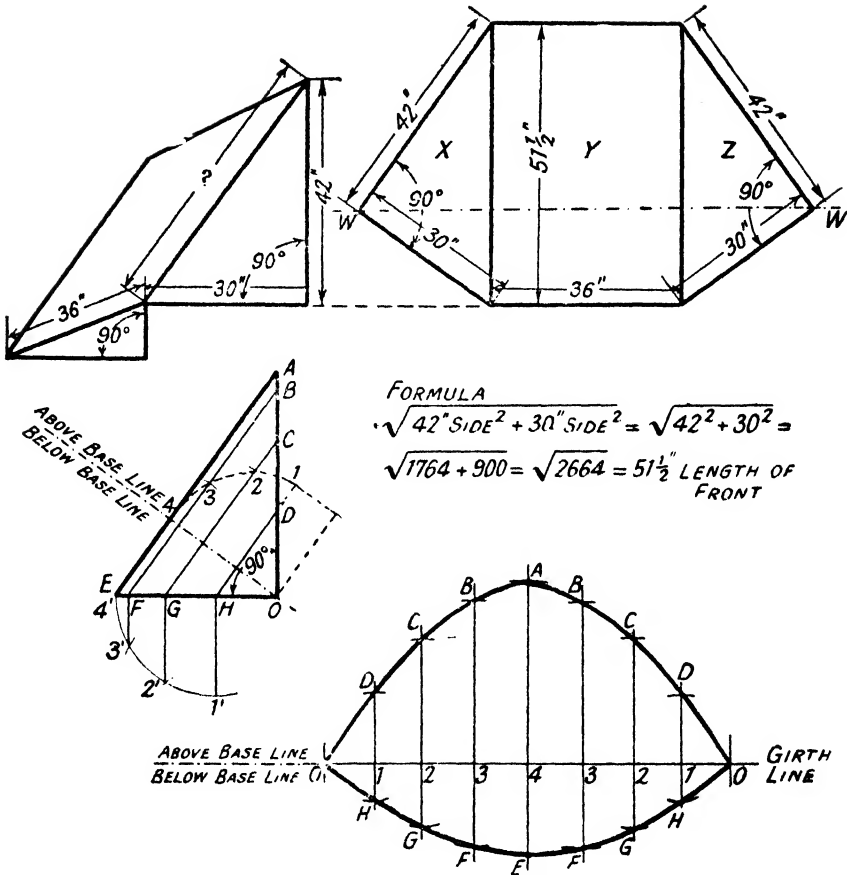


Fig. 15.—PATTERNS FOR SQUARE AND ROUNDED HOODS

2'-G, and 1'-H on the bottom line quarter-circle and transfer them so as to form dotted apparent quarter-circle above the base line.

It may be thought that it is unnecessary to draw the lower quarter-circle, but if the reader will measure along the base line from 4 to H-1 it will be seen that the distance is much shorter than 4'-H along the bottom line of the hood.

The pattern is produced by first drawing the base line and at right angles drawing the line A-4-E. Space off along the base line (now the girth line) eight spaces equal to sections on the lower quarter-circle periphery and *not the lower edge of the hood*. On the lower side of the girth line measure off 4-E, 3-F, 2-G, and 1-H, on one side of the line A-4-E, and on the other side repeat the process. These measurements will be obtained from the dotted base line to the lower edge of the hood.

Above the base line (now the girth line) space off 4-*A*, the length of which will be on the line 4-*A* from above base line to the top edge of the hood. The others, respectively, will be 3-*B*, 2-*C*, and 1-*D* repeated on both sides of line 4-*A*. Freely drawn-in lines from 0 to 0 above and below the girth line will give the true shape of the hood.

Allowance for Wiring Edges of Sheet-metal Articles (Fig. 16)

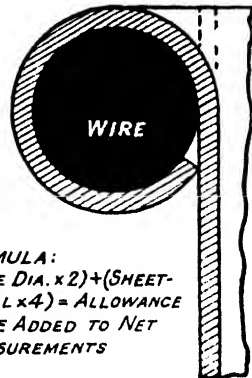
The formula shown in the Fig. 16 should be guide enough for all practical purposes, but an example may be of use: Assume a metal tray made from 20-gauge sheet steel has to be edged with $\frac{1}{16}$ -in. wire. This resolves itself into $(.0625 \times 2) + (.0392 \times 4) = .125 + .1468 = .2718$, or between $\frac{1}{4}$ in. and $\frac{3}{8}$ in. Whatever the diameter of wire or thickness of material, the same rule applies, and this is the extra length that must be added. Care must be taken to make very accurate measurements, otherwise the wire will not have sufficient material to hold it in place, or the ultimate measurement of the box will be incorrect.

Rule for Making Metal Clips and Bands (Fig. 17)

The average mechanic is often at sea when it comes to making a simple clip or band for a pipe, but if the following rule is observed the clip should be a perfect fit. In the example (Fig. 17) we have a 2-in. bar with a clip $\frac{1}{4}$ -in. thick. The calculation is based upon the fact that the only portion of the band that can be relied upon for correct measurement is the centre line of the band itself. Under the rule in Fig. 17 is a piece of straight metal with two lines through it at right angles. If the metal is bent, the imaginary lines will then be as the second sketch of the example, wherein the distance has remained constant on the centre line, contracted on the underside and expanded on the upper side. It will be seen that the centre line only is the place where all calculations must start. With a $\frac{1}{4}$ -in. thick clip on a 2-in. bar the actual diameter becomes $2\frac{1}{4}$ in.

Square-tapered Box with Unequal Sides (Fig. 18)

Firstly draw the plan of the desired box (Fig. 18) and see that all the side edges *A-E*, *B-F*, *C-G*, and *D-H* meet at a common centre *O*, otherwise it will not be possible to construct the box. Having made sure of the correctness of the design, then draw the elevation and extend the two sides to the point *O'*. Extend the base line so that the edges *O-E-A*, *O-F-B*, *O-G-C*, and *O-H-D* can be spaced along it as shown at *B*, *A*, *C*, and *D*. On another base line extended along the top of the box space off *O-E*, *O-F*, *O-G*, and *O-H*. With *O'* as the



FORMULA:
 $(\text{WIRE DIA.} \times 2) + (\text{SHEET-METAL} \times 4) = \text{ALLOWANCE}$
 TO BE ADDED TO NET MEASUREMENTS

Fig. 16.—ALLOWANCE FOR WIRING EDGES OF SHEET-METAL ARTICLES

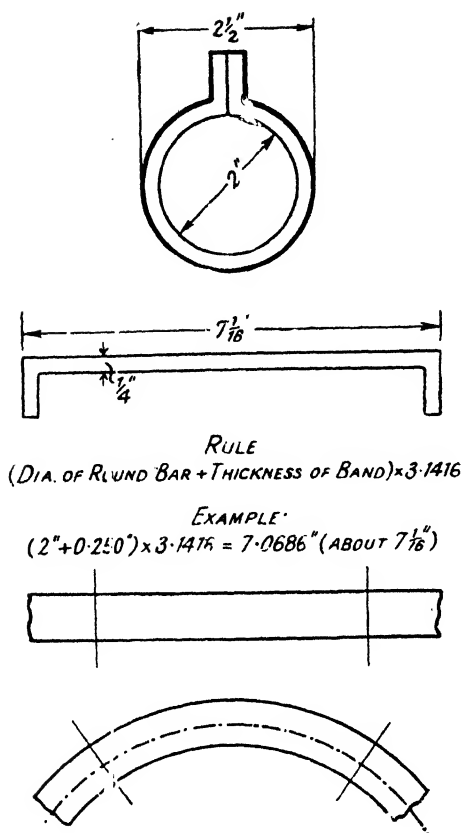


Fig. 17.—RULE FOR MAKING METAL CLIPS AND BANDS

centre, draw circles equal to the places where the letters *B*, *A*, *C*, *D* intersect the base line. Then carry out the same process with the same centre, but using *F*, *E*, *G*, *H* on the top base line. At any convenient position draw the line *A-E* radiating from *O'* and starting on radius *A* and finishing on the smaller radius line *E*. This, of course, will be the edge of the box at *A-E*. With one leg of the dividers at the corner *A* on the plan measure off *A-B*. Then set one leg on *A* on the end of the line drawn on the radius *A* to *E* and measure off the point *B* on the radius *B*. Measure off the distance *B-C* on the plan and space *C* on the radius line *C*. The same with *D* on radius line *C* and *A* on the radius line *A*. If lines are drawn from these points to the centre *O'* and the points *F*, *G*, and *H* marked off on the same lettered radius lines, the edges of the box can be drawn in. On connecting up the points *E-F*, *F-G*, *G-H*, and *H-E* and forming the top edges of the box opening, they will all be found to be the same length, or should be so, if the measuring has been accurate and

the correct radius lines have been selected; that is *E-F*, or *F-G*, or *G-H*, and *H-E*.

Rectangular Flue (Fig. 19)

Fig. 19 has been specially constructed to give some idea of requirements in buildings where air conditioning is installed. This drawing is based on a required change in shape, but retaining the same internal area. The bottom flue is 9 in. square, whilst the top part is 12½ in. by 6½ in. The pattern has been so arranged that it can be cut out of one piece of plate and with as few joints as possible. The pattern layout is quite simple, especially with the back and one of the sides. The caution in this instance is not to forget to construct side *A* and front *F* at right angles

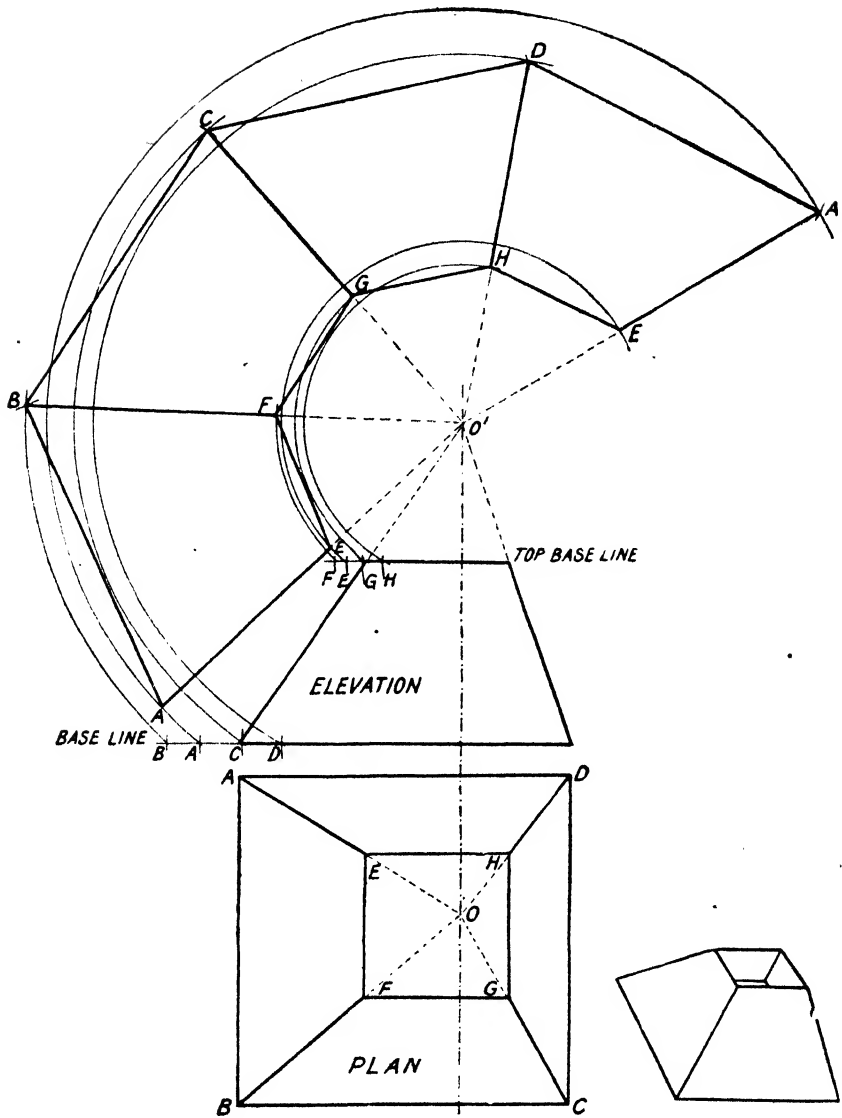


Fig. 18.—PATTERN FOR SQUARE-TAPERED BOX WITH UNEQUAL SIDES

to the sides immediately against them. By so doing it brings the edges back to square, otherwise the layout is quite simple, although a very good example of the class of sheet-metal work the general engineers' shop is called upon to carry out from time to time.

Blacksmith's Hood and Flue (Fig. 20)

The example in Fig. 20 is a further step in laying out patterns that are curved and have to snugly meet the flue that will be fixed. There is no difficulty in producing such a pattern if the instructions and rules are fully adhered to.

In the first instance, draw an accurate sketch of half of the hood plan. Draw a line at *C*, thus quartering the actual flue hole. Once again section off at *D*. The extreme ends of the rounded corner are then denoted by the dotted lines, the intersection producing a centre from which the dividers can be used to space off the edges of the hood as 2, 3, 4, and 5. Lines are then drawn through the flue centre from point 5 and the point *C* from 2. These lines will meet at the point *X*, and it is from here that a line parallel to 0-6 is drawn and on which is built the elevation as shown.

In other instances it has not been essential for the elevation to be definitely placed, but here the relative positions of both plan and elevation have a marked effect on the correctness of the pattern.

Having drawn the elevation in its correct position, continue the line *A'-6* until it intersects another line drawn from *X*. This line is parallel to 0'-0' and will intersect *A'-6* at *X'*. Using *X* as a centre, run radius lines from 2, 3, 4, and 5 to the base of the elevation at 2', 3', 4', and 5'. Line 6-6 is not curved, as it already shows the true position of 6 on the half-elevation. From the points just mentioned run up lines to *X'*.

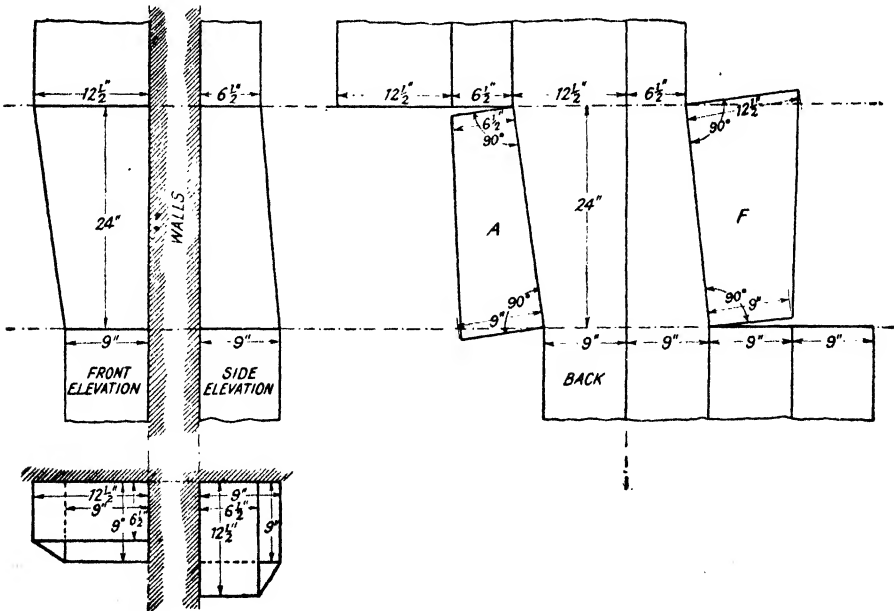


Fig. 10.—PATTERN FOR RECTANGULAR FLUE

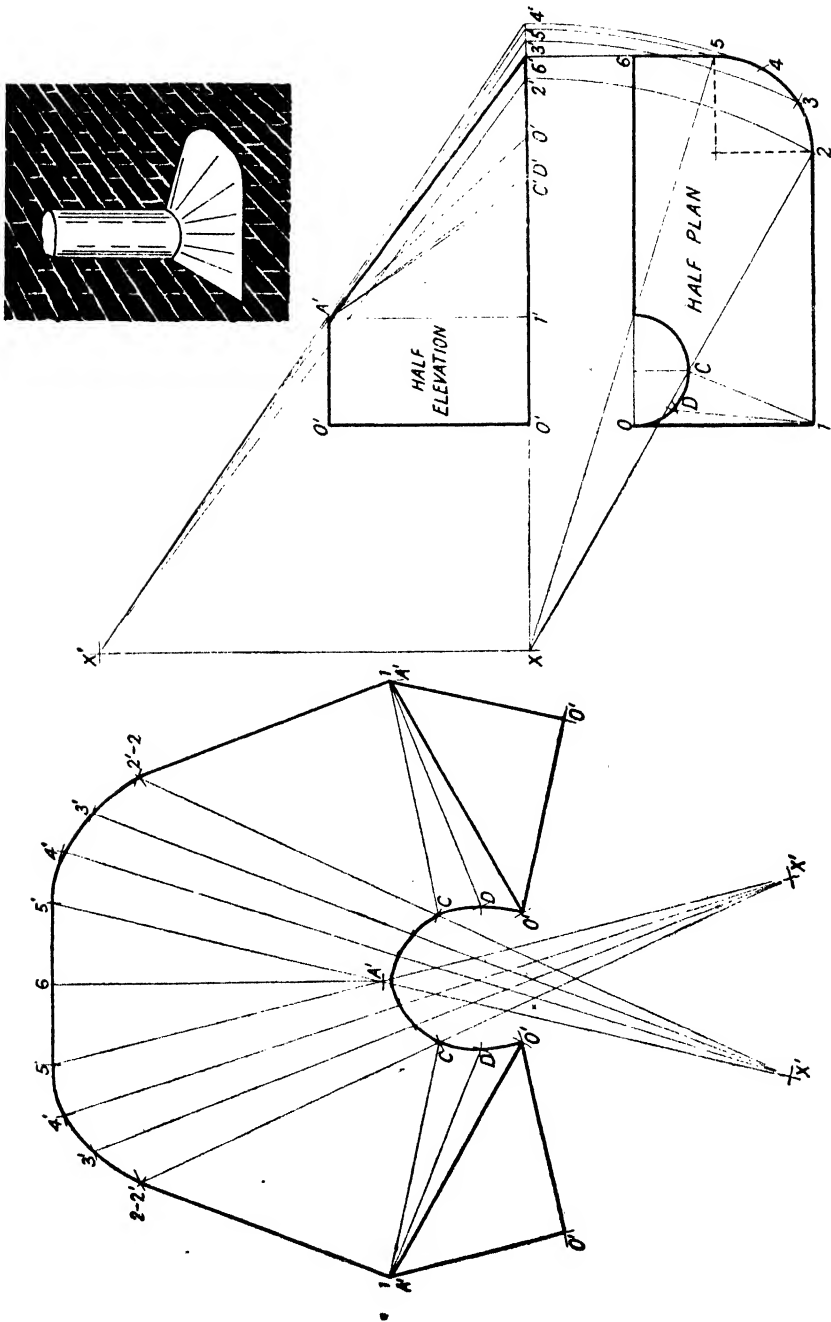


Fig. 20.—PATTERN FOR BLACKSMITH'S HOOD AND FLUE

From the half-plan mark off the distance 0-1 from 0' on the elevation to 0' along the base, the same with 1-D and 1-C, and mark them D' and C' respectively. Draw three lines from A' to 0', C' , and D' respectively.

Forming the Pattern

In commencing the pattern, first draw a line equal in length to $A'-6$ on the elevation, and at right angles to this line on the point 6 draw another. Mark off on either side the distance 6-5, *taken from the half-plan*. Mark the points 5'. From the two points 5' run down lines through the point A' and then open out the dividers and measure off from 5' on the elevation the distance 5'- X' , and transfer this value to the extended 5'- A' on the pattern. As there are two of each figure (one on either side of 6) we shall also have two points marked X' on the pattern. Set the dividers to 5-4 on the quarter-circle on the plan and mark off 4' as done with 5'. Take the distance 5'- X' on the half-elevation and from X' on the pattern intersect the radius drawn from 5' and produce the definite point 4'. Carry out the same with 3' and 2'.

We shall now have four lines radiating from each centre X' . Mark off the size of the hole in the pattern by distancing X' to line 0'- A' on the top of the elevation where the respective lines pass through the elevation of the flue.

It will be seen that the line $X'-2'$ on the elevation passes some distance away from the others through 0'- A' . Very carefully mark the distance at C on both lines on the pattern, as these points now become centres of the remaining vital measurements. At the points 2/2' on the pattern set one leg of the dividers and radius a distance equal to 1-2 on the half-plan (be sure the measurement is taken from the half-plan). Having scribed the part circles, measure off A' to C' from the elevation. With one leg of the dividers on the point C on the pattern intersect the part circle and draw a straight line from 1/ A' to 2/2'. The same on the other side of the pattern. On reflection, it will be recognised that these straight lines will form the sides of the hood marked on the half-plan as 1-2.

Completing the Hood Pattern

At the points 1/ A' on the pattern scribe off the distances A' to D' from the half-elevation. Set the dividers to the distance $C-D$ on the semicircle representing the flue on the half-plan and intersect the line 1/ A' to D at D on the pattern. From 1/ A' *again* measure off a point equal to $A'-0'$ from the half-elevation, then space from D on the pattern the distance $D-0$ from the half-plan, after which mark both spots 0'. From the points 0' on the pattern radius off the lengths 0' to 0' from the elevation. Returning to 1/ A' on the pattern, intersect the last lines with the distance 0 to 1 from the half-plan.

Connect up the points of intersection and the result will be the complete hood with back plate that will only need joining down the centre.

Chapter III

CUTTING AND FORMING SHEET METAL

THE tools used for working sheet metal may be divided into two distinct sections, i.e. cutting tools and forming tools, and it is proposed to give a description of each type and their use.

CUTTING TOOLS

Guillotines

Guillotines, usually treadle-operated machines, are fitted with a long straight blade, used for making straight cuts up to approximately 4 ft. in length, on metal not exceeding 18-gauge thickness.

Fig. 1. --- CUTTING SHEET METAL (1)

Marking out the hole to be cut.



Fig. 2. --- CUTTING SHEET METAL (2)

Making hole to start pneumatic hand cutter (see Fig. 3).

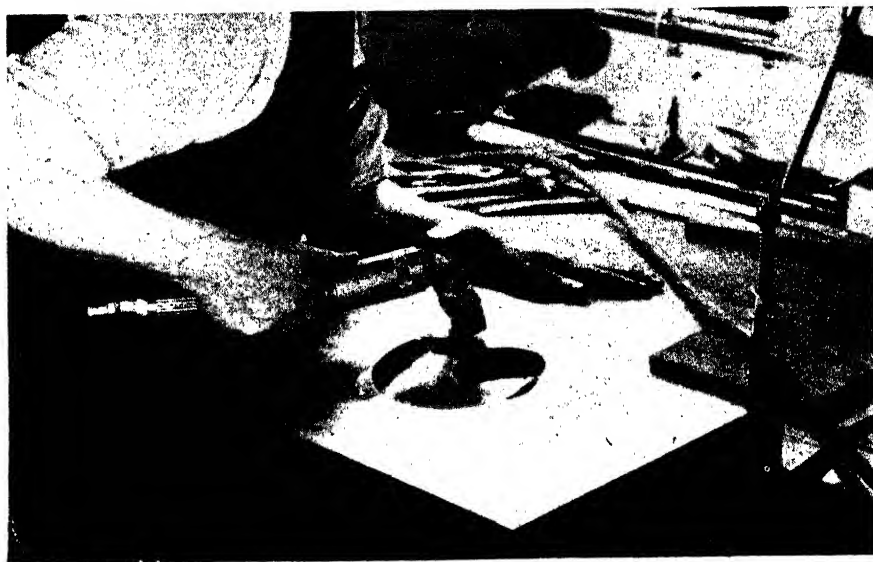


Fig. 3.—CUTTING SHEET METAL (3)
Sheet-metal plate with pneumatic power shears.
(By courtesy of Tecalemit, Ltd.)



Fig. 4.—CUTTING METAL SHEET TO SIZE ON TREADLE GUILLOTINE SHEARS
(By courtesy of Tecalemit, Ltd.)

Snips

Several types of snips or shears are to be encountered in sheet-metal work, each being intended for use on a different class of work. Straight snips are used to make straight cuts and also for cutting outside curves. Bent snips are specially intended for cutting internal curves, and Universal snips, as the name implies, are intended for universal use, the blades being thin and "backed off" to allow an easy passage over them for the metal.

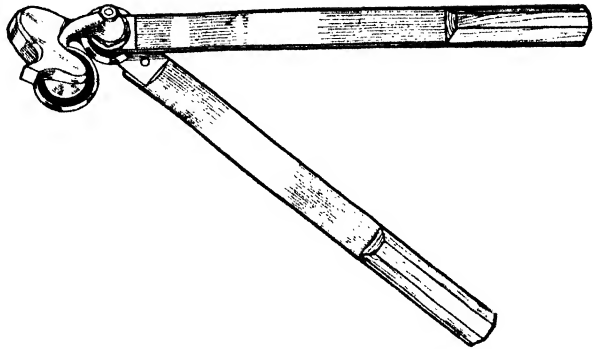


Fig. 5.—"EZISHEER" SHEET-METAL SCISSORS
Capacity up to 16 gauge. (Buck & Hickman, Ltd.)

These are used for cutting any curve or shape in flat work, and may be obtained to cut either right hand or left hand.

French snips consist of straight snips with off-set blades and "swept" cutting edges, and are intended for cutting shaped panels, being manufactured in both right- and left-hand styles, so that panels can be cut *in situ*. The correct hand to use for any job is that which will curl the waste metal in the opposite direction to the curve of the panel.

Jewellers' bent snips are light bent snips which are extremely useful for "cutting in" aircraft cowling, and for cutting holes in light-gauge metal and similar light work.

Hand-lever and Rotary Shears

Hand-lever shears are light toggle-jointed bench shearing machines for cutting metal up to 10-gauge thickness ($\frac{1}{8}$ in.), this gauge being too heavy to be conveniently cut with snips.

Rotary shears are entirely different from any type previously mentioned, as they consist essentially of two hardened steel wheels attached to geared shafts, arranged so that the cutting edges slightly overlap, thus producing a shearing action. A clean cut of any desired length can be obtained, but the width of the work is limited by the distance from the wheels to the frame, this space being known as the "throat." These machines are used for cutting ribbons, square internal holes, etc.

Throatless Rotary Shears

To overcome the limitations imposed by the frame of the slitting shears, a throatless shearing machine has been built with a frame so designed that the metal passes on either side, in the same way that it passes over the back of the blades of universal snips. The bottom wheel

is serrated, and thus cuts an impression in the waste material, thus feeding the metal through the wheels with a rack-and-pinion action. The machine is extensively used for cutting shaped panels from complete sheets, but as the work is fed through the wheels (and guided) by hand, it cannot be regarded as a precision cutting tool, except when used by highly skilled operators. Its main use is to roughly cut the panels to shape, leaving sufficient material on the edges to allow for trimming with snips.

A circle cutter is a rotary shearing machine with provision made for carrying the work about an adjustable centre. By locking the distance between this centre and the cutting edges, a circle of any desired radius may be cut by merely revolving the wheels, the operation becoming automatic as the metal feeds past the wheels.

Shear-type Nibbler

The shear-type nibbler is a small, power-driven bench machine used for rapidly and accurately cutting metal up to 16-gauge thickness. Actually this is a type of short-stroke power shear, fitted with a rapidly oscillating cutting blade, so that each stroke makes a cut of approximately $\frac{1}{8}$ in. in length. The speed of the blade is between 1,200 strokes and 1,400 strokes per minute, and the linear cutting speed is in the region of 6 ft. per minute. Usually the metal is fed "free hand." The machine can be used for all cutting-out purposes, and in particular is largely used for cutting out from the sheet motor-body panels and similar work. A clean edge, which does not require further treatment, is produced by the blade.

Punch-type Nibbler

For metal from 16- to 10-gauge thickness a punch-type nibbler is often used, consisting of a small punch and

die which punches out a straight-sided hole (Fig. 6). The punch oscillates at 300 strokes to 350 strokes per minute, and as the work is fed through the machine, the holes overlap to cut a straight-sided slot, which leaves a clean outline. It is usual practice to clamp a thick pattern to the work and guide it to the required curve by keeping the edge of the pattern bearing against the punch. Heavy-duty nibblers work on similar principles to the machine described above, but cut a round hole of about $\frac{1}{4}$ -in. diameter, being used for plate up to $\frac{3}{16}$ -in. thickness.

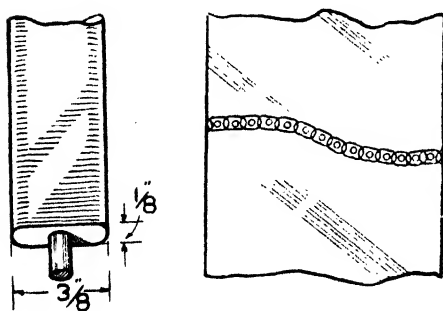


Fig. 6.—PUNCH-TYPE NIBBLER FOR CUTTING METAL FROM 16- TO 10-GAUGE THICKNESS

Showing how overlapping holes produce a continuous cut.

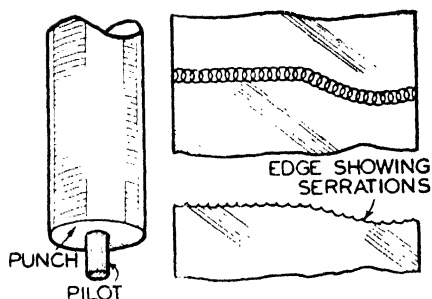


Fig. 7.—HEAVY-DUTY NIBBLER FOR CUTTING PLATES UP TO $\frac{3}{16}$ IN. IN THICKNESS

The serrated edge left by the tool must be cleaned up with a file.

The serrated edge left by the tool must be cleaned up with a file. A pilot in the centre of the punch regulates the depth of each "bite," these being made at the rate of 120–150 per minute (Fig. 7).

Using Chisel for Cutting

In the absence of suitable shears, the ordinary cold chisel can be used for cutting heavy sheet and plate metal, and also for cutting out holes to a finished size. The edge should be ground slightly convex (Fig. 8), so that the corners do not "dig in" and to enable a line to be followed by rolling the chisel edge along the line as the cut progresses.

Hollow Punch

A hollow punch is a circular cold chisel used for cutting out round holes in sheet metal, the work being laid on a lead block (Fig. 9). Unfortunately the cutting action stretches the edge of the hole, thus producing a rounded burr which makes this method undesirable for many classes of work. However, if fittings are to be soldered in the hole, the burr is of definite advantage, as it gives a larger area of metal on which to solder (Fig. 10).

Punch and Die

The most suitable method of producing a hole without a burr is undoubtedly by the use of a punch and die mounted in a fly press or other suitable machine. It is usual practice to have the punch made with a pilot pin turned on the end, so that it will engage in small pilot holes drilled in the centre of the holes to be cut. By this means each hole is quickly located and punched in the correct position (Fig. 11).

FORMING TOOLS

The tools most commonly used for shaping sheet metal are hammers, mallets, and bench tools of the anvil type, over which the material is

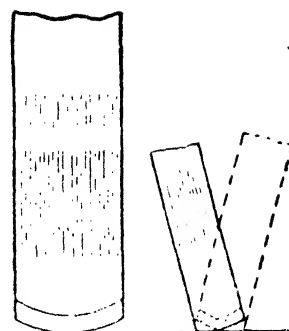


Fig. 8.—USING CHISEL FOR CUTTING SHEET

Note rolling motion of chisel.

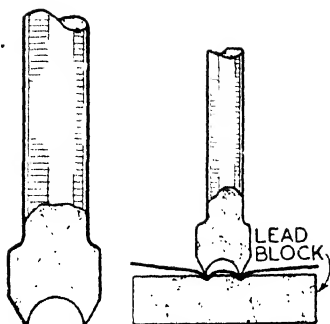


Fig. 9.—HOLLOW PUNCH FOR CUTTING OUT ROUND HOLES

Showing distortion of sheet produced by this method.

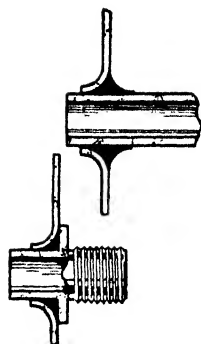


Fig. 10.—SHOWING TUBE AND CONNECTION SOLDERED IN PUNCHED HOLE

formed to shape. These latter are known as stakes, and are usually named after the particular use to which they are put, or after objects which they resemble. The stakes are provided with tapered square shanks, to fix into square holes cut in the bench, or sometimes they are made to fit in the end of a mandrel.

Hammers

Of the hammers, the most useful shape is the “square-faced” type, weighing 12 oz. to 16 oz., having two flat faces, one circular and the other square. This is used for wiring, planishing, and all purposes where the metal is most suitably worked with a flat-faced hammer.

A planishing hammer is used for “finishing” panels by hammering

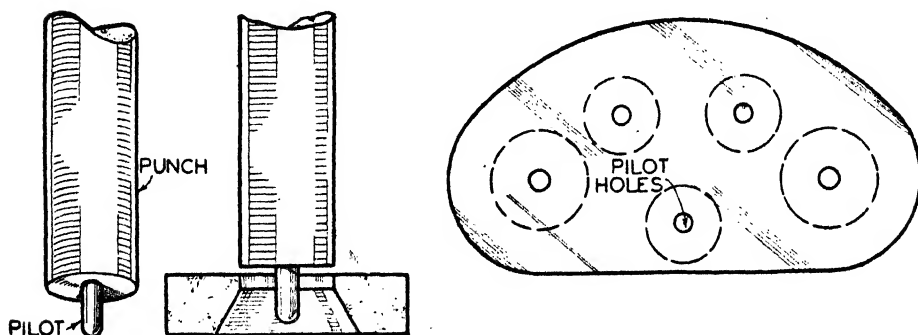


Fig. 11.—PUNCH AND DIE FOR USE IN FLY PRESS

On right—tank baffle with pilot holes drilled to allow each hole to be quickly located and punched in correct position.

them on a piece of shaped metal, known as a "head." The weight ranges from 8 oz. to 16 oz. for use with sheet-metal, and up to 3 lb. for plate setting. The faces of the hammer are round and, in comparison with the weight, fairly large. For sheet-metal work the usual diameter is between 1 in. and 1½ in., one face being perfectly flat for planishing convex surfaces, whilst the other is curved slightly outwards to enable its being used for working from the inside of shaped panels or on flat surfaces where it would be difficult to strike a truly flat blow with the flat face of the hammer. In order to impart a good surface finish to the metal, the hammer faces should be always polished and smooth, this usually being done by occasionally rubbing the faces on a hand buff, consisting of a piece of soft leather tacked on to a wooden backing or mandrel. Crocus powder or other suitable polishing powder is sprinkled on the leather. A polished hammer will impart its polish to the work with every blow, and, conversely, every blemish on the face will be imprinted on the work.

The faces of a stretching hammer are rounded in one direction and straight in the other, the action being to displace metal in the form of a shallow trough, the metal so displaced extending the surface in one direction only. Principally, this hammer is used for stretching flanges, but it is useful for all inside shapes requiring stretching in only one direction. In certain cases, where the hammer shaft prevents the use of the standard stretching hammer, a special "two-way" type is used with one face across and one face in line with the shaft.

Blocking hammers are a group of hammers used for shaping sheet metal (particularly tinplate) on a wooden block, consisting usually of a section of a tree trunk with depressions of various depths in the end, the metal being beaten to shape in one of the depressions with a suitable hammer. Usually the weight of the hammers is between 1 lb. and 5 lb., and the two faces are convex, with rounded edges.

Hollowing hammers are used in a similar manner, but are provided with large hemispherical faces on a long head, in order to provide the necessary clearance when shaping deep articles.

Studding hammers are light and long-headed, being used to form local depressions in a larger job.

Paning hammers are specially designed for paning down the edges of joints situated in confined positions (e.g. close to the wall of a cylindrical article) and also for tucking metal behind a wire so that a neater finish can be obtained on larger wiring jobs.

Mallets

Boxwood mallets are used for operations where it is desired to avoid stretching or contracting (known as tucking) and also for wiring. Bossing mallets are egg-shaped, and are used for shaping soft metals (such as

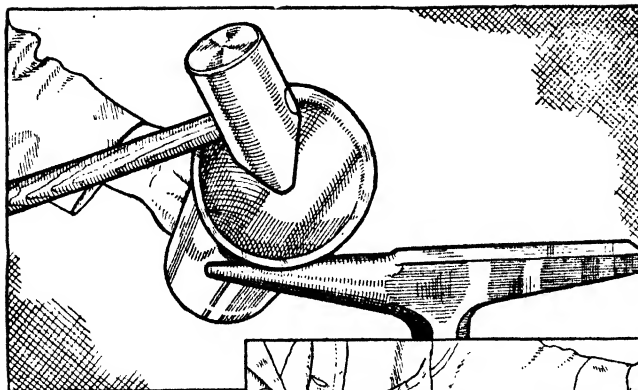
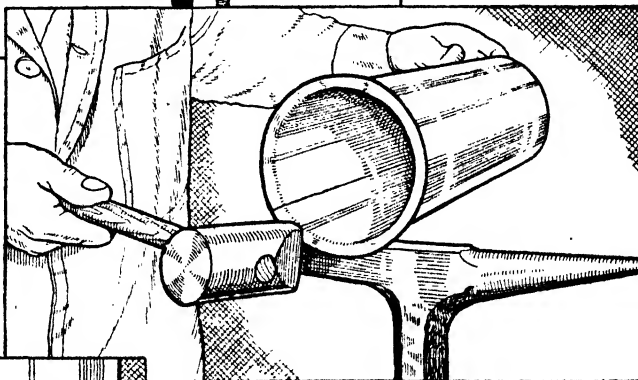


Fig. 12 (left).—
FORMING FLANGE
ON COPPER PIPE
—FIRST STAGE

Using hardwood mallet on rounded portion of bick iron until sufficient metal is stretched outwards.

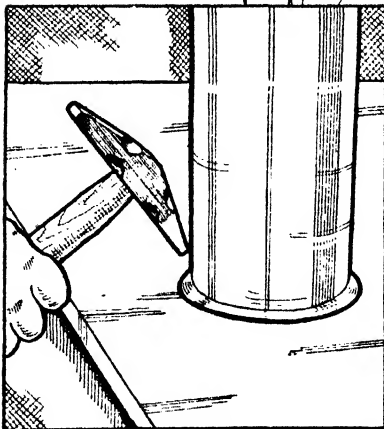
*Fig. 13 (right).—*FORMING FLANGE—SECOND OPERATION

The pipe is then placed on the square edge of the bick iron and gradually worked back flat, using the wedge-shaped mallet.



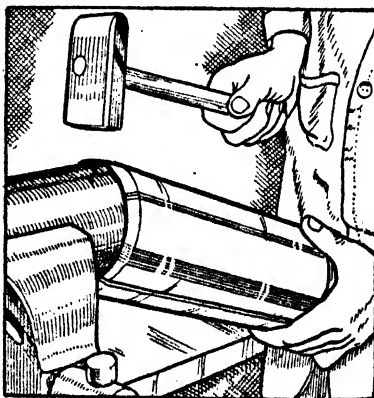
*Fig. 14 (left).—*FORMING FLANGE—FINAL OPERATION

A paning hammer being used to work down the neck of the flange against the pipe and to remove any irregularities.



*Fig. 15 (right).—*SHRINKING A SPIGOT OR SLIP-IN END ON PIPE

The pipe is held at an angle to the mandril and, using a mallet, the pipe end is worked over in ripples to form a taper. The ripples are then gradually worked out.



aluminium) on a sandbag and also for stretching over rounded edges in concave curves (e.g. turning in the lights for motor bodies).

BENCH TOOLS

Mandrel

The most useful of the bench tools is the cast-iron mandrel, consisting of a bar approximately 4 ft. in length, one end having a rounded top face for shaping rounded jobs and the other a flat top face, with slightly tapered sides and end, this end being used for shaping square work. A square hole in this latter end is provided to hold small interchangeable heads or blocks of shaped metal.

Bench Anvil

The bench anvil is a heavy bench tool having a flat face of "D" shape, and is used for general hammered work on flat surfaces.

Stakes

The anvil stake is a lighter form of the bench anvil and is used for similar work.

Bick irons, sometimes known as beak irons, resemble a blacksmith's anvil in appearance, but are lighter, longer, and more slender.

The square end is used for forming channels, narrow boxes, etc., while the "beak" is used for forming round tapered work.

Side stakes, known also as pipe stakes, consist of a round bar attached at right angles to an upright support. These are used for small round forms, whilst the end, which is cut off at an angle, is used for turning the edges of discs and similar articles in preparation for wiring and jointing.

Funnel stakes, as the name implies, are used for forming funnel-shaped articles, and consist of a half-conical section of steel attached to an upright support.

The extinguisher stake is a smaller edition of the bick iron, and was originally used to form the cones used for candle extinguishers, but is now employed for forming small funnel-shaped and conical sections, and has, in addition, a useful narrow flat face.

Crease irons are provided with a rectangular face, semicircular grooves of various radii being cut across one half, while the remainder is left flat. The corners of pans and trays can be conveniently creased, and wired edges, etc., set on the grooved end, while box sections may be formed on the plain end.

Hatchet stakes consist of sharp-edged stakes, used for forming edges on work with straight sides or with inside curves which are sharper than a right angle. This tool is useful for work whose shape or position prevents the use of a folding machine, such as sharpening up rounded bends and forming the sides of boxes, trays, etc.

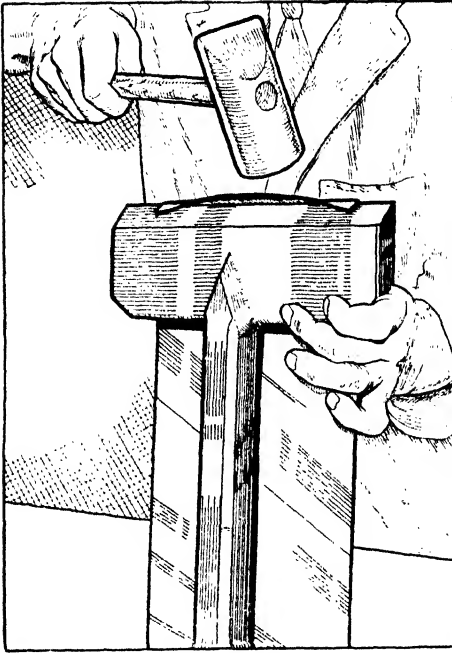


Fig. 16.—USE OF THE HATCHET STAKE

Showing how the edge of a small sheet of metal is turned in readiness for a welted or grooved seam by using a hatchet stake.

Half-moon stakes are curved, sharp-edged stakes used to form the edges on outside (convex) curves, discs, etc.

The dripping-pan stake and round-bottoming stakes are flat square-faced and flat round-faced stakes respectively. They have many uses apart from those for which they were originally designed, including edge forming and seaming square and round articles, as well as general use where a flat-faced tool with plenty of clearance is required.

Panel Heads

Panel heads are convex blocks of steel or cast iron fitted with square shanks to engage in a square hole in a wooden mandrel or horse. They are made in various sizes, shapes, and contours for forming and planishing the varied shapes into which sheet metal can be

beaten, and are not standardised to the same extent as the bench tools. Panel heads are named from their shape or use, such as a raising head (used for shaping panels by planishing with a hammer), oval head, long head (from the shape), wing head (from its uses), etc. For tucking the edges of a panel when forming the shape, a head should be used which is flatter than the shape of the finished panel, and when planishing, a head which conforms to the shape of the job as nearly as possible (but slightly more convex) will give the smoothest finish.

The machines used in sheet-metal work include folding and bending machines, wheeling machines, beading, and swaging machines, etc., and these are dealt with in the following chapters.

Chapter IV

BENDING AND FOLDING BY MACHINE

THE essential factor in producing a clean bend on sheet metal is that the edge or blade over which the metal is bent should be straight, smooth, and fairly sharp (a small radius is necessary to produce the bend), and that the pressure applied to bend the metal over this edge should be equal throughout the length of the bend.

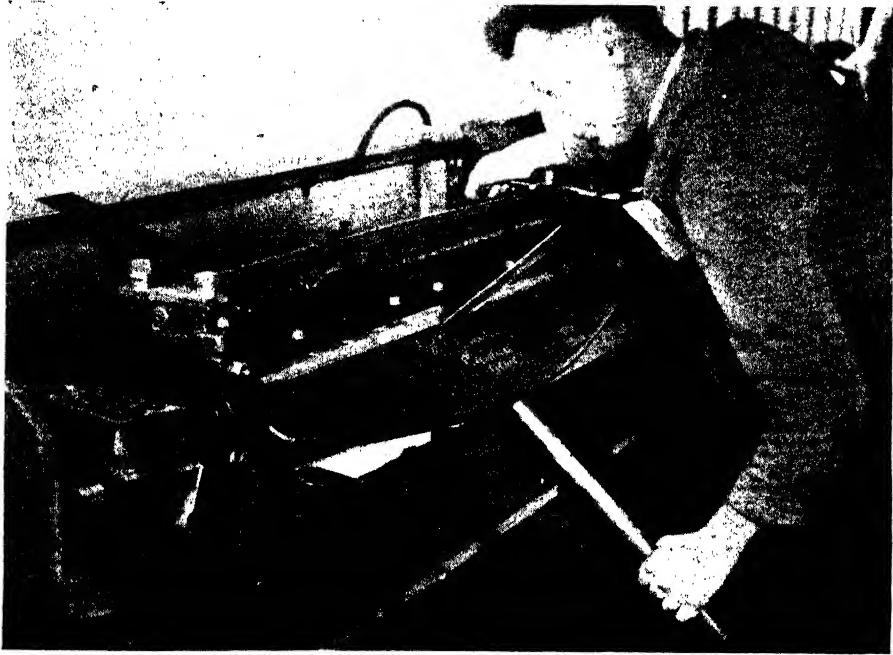


Fig. 1.—SMALL BENDING MACHINE FOR SMALL PARTS

Angle Bender or Cramp Folder

The most generally used machine for bending sheet metal up to 16-gauge thickness is the angle bender or cramp folder (Fig. 2), consisting of a clamp to which is attached the blade around which the metal is bent. This is operated by a hand lever fastened to an eccentric, to apply the necessary pressure to clamp the work to the bed of the machine in order

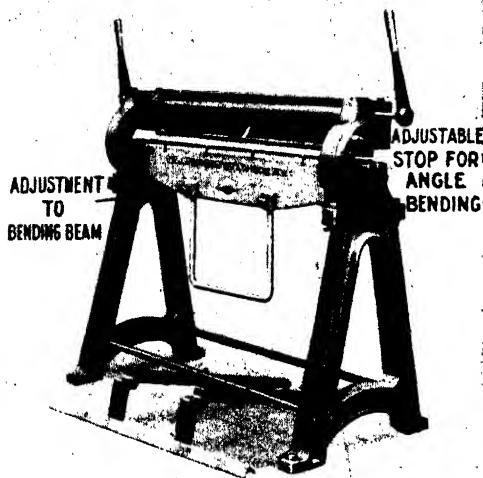


Fig. 2.—ANGLE BENDER OR CRAMP FOLDER

Note the four slots in the bending beam to clear the front hook guides and also the back guide, dismantled, on the floor.

(F. J. Edwards, Ltd.)

to prevent movement while bending is in progress. The actual bending is done by swinging up the front part of the bed on a hinge centre, in line with the bend.

In practice it is only necessary to clamp the metal in the machine so that the edge of the blade coincides with the line on which the bend is to be made, and then to swing the bed up to the required angle, which may be anything from a "set," i.e. a very small angle, to 20° . This is the first stage in the production of a "double-edge finish" and an edge used for wiring.

Provision is made for repetition work by the fitting of a guide at the back of the machine

for bends of more than 4 in., and hook guides, running in slots, in the front of the machine for small bends occurring near the blade. These front guides are let into dovetail slots, where they slide for adjustment, this being made independently on each hook by means of a knurled handscrew situated at the rear of the bed. In use, the hooks (usually only two are required, one at each end of the work) are set to stop the edge of the sheet at a predetermined distance from the bend line. The work is fed in from the rear until it engages the hooks, and is then cramped and folded.

The back guide, used for bends occurring too far from the edge to be dealt with by the front guide, consists of two arms with a T slot running throughout their length. Across these is bolted the guide, which may consist of a cast-iron bar fitted with extension lugs to bring the guide-face close up to the back of the machine, or it may simply be a length of angle iron bolted to the T slots. The sole function of this guide is to stop the edge of the sheet at a definite distance from the blade when the bend is made. An adjustable stop is also fitted, so that the bed can be set to swing to the same predetermined angle each time. This "angle stop" consists of a collar and bolt, sliding in a T slot shaped in the form of an arc, the slot being fitted on to the end of the machine. A lug on the swinging bed engages with this collar and is thus prevented from further angular movement.

Hand-operated cramp folders are usually from 3 ft. to 4 ft. in length

but are often made with open ends, so that bends longer than the bed can be made by moving the work and making the bend in two or more operations. Power-driven machines are built to deal with $\frac{1}{8}$ -in. plates up to 10 ft. in width.

Adjustment is provided for bends of various radii and thicknesses of metals by raising or lowering the swing bed with two thumbscrews. For sharp bends on thin metal the bed is brought up level with the blade, whilst for thicker sheets or larger radii the bed is lowered so that it describes a small arc around the edge of the blade when it is swung up. For occasional radiused bends it is general workshop practice to wrap a piece of sheet metal around the blade, to "round off" the edge over which the metal is bent. For repetition work on radius bends the standard blade should be replaced by a special blade machined with the correct radius. It is not essential for this blade to extend the whole width of the machine, so long as it extends a short distance over both sides of the work.

Larger angle-bending machines have provision for bending radii by inserting rollers in the front edge of the clamp, which is operated by a handwheel and vertical screws, in order to give the greater pressure required for longer bends.

Power-driven Angular Bending Machines

One type of power-driven angle bender utilises a top cramp blade of narrow vee section, with bending beams on each side, giving a range of angles between 180° and 35° . Swing ends are fitted to enable work which has been folded to closed or intricate shapes to be withdrawn from the end of the machine, to eliminate the distortion caused by taking it out from the front or rear. This type of machine is made to deal with plate up to $\frac{3}{8}$ in. thick by 4 ft. wide, whilst the largest machines will bend $\frac{1}{4}$ -in. plates up to 12 ft. in width.

Another type of machine is the universal swing beam folding and bending machine (Fig. 3), which is a heavy-duty hand machine with a counterbalanced swing beam. The capacity is 4 ft. by 14 gauge, and it is supplied with a series of cramp blades giving square and radiused bends, a stepped blade which gives clearance at the back for folding narrow channels and moulding sections. An interesting roller attachment is supplied, around which metal may be formed into a large radius bend, or by moving the metal around the roller during the operation a complete tube can be obtained in three operations.

In using bending machines for compound bends, skill and care are necessary if a true shape is to be obtained. The bends are worked in such order that one bend does not prevent another from being made, and the thickness of the metal must be taken into consideration in order to obtain a true section. Because of their versatility cramp folders are the most useful of bending machines for general work.

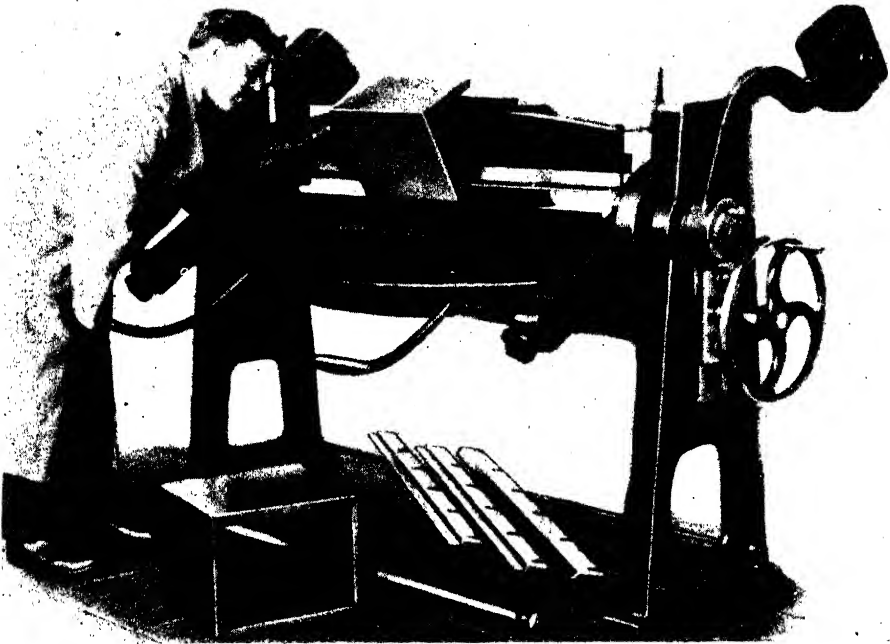


Fig. 3.—UNIVERSAL SWING BEAM FOLDING AND BENDING MACHINE

Note the screw-operated cramping beam, counterbalanced bending beam blades for square bends and bends of small radius, and the roller attachment for bends of large radius and tubes.

Folding Machines

Folding machines are used for folding edges of sheet metal, up to 20 gauge, so that they are doubled back. These machines are made in various widths from 12 in. to 36 in., and are constructed so that they can be bolted on to the bench. Two different types are made with either flat or roller beds, the former, which only has adjustment for the size of the fold, being mainly used for tinwork.

In addition to this, the latter type (Fig. 4) has an adjustment on the roller which can be made to act as a stop for bends not greater than a right angle and for the radius of bend or thickness of metal for edges folded right over. For sharp folds on thin metal the roller is brought up to the blade and set with just sufficient clearance to allow the metal to pass between the roller and blade. For thicker materials or rounder bends the roller is moved back from the blade, thus giving more clearance for the heavier (i.e. thicker) materials, and, by making contact with the metal farther from the blade, gives a rounded bend.

Unlike the cramp folder, the work is not gripped, but the edge is

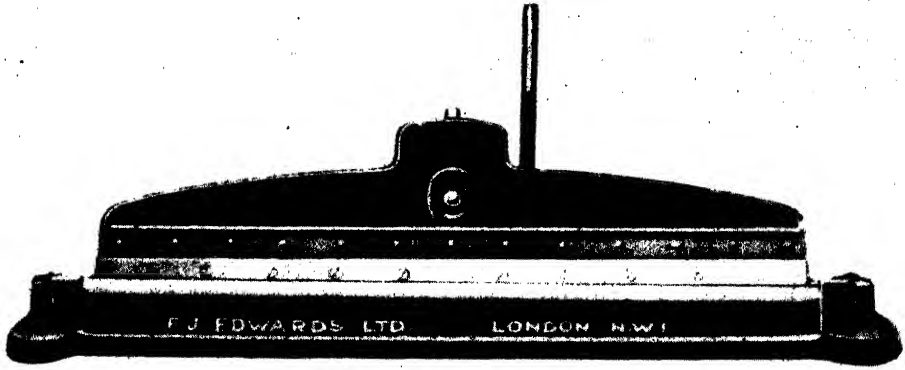


Fig. 4.—ROLLER BED FOLDING MACHINE

slipped into a slot between the bed and blade of the machine, made by separating them with packing pieces. The back of the slot is formed by the adjustable guide, which extends past the packing pieces, as a series of fingers. The guide is adjustable and slides backwards and forwards on a wide register to keep the end parallel with the blade. It is adjusted with a thumbscrew at the back of the blade and can be locked, with a setscrew, in any position.

The whole of the back part of the machine hinges on large pins set in line with the edge of the blade over which the metal is folded. To use the machine a line is marked on the edge for the fold, and the edge is slipped under the blade until it rests against the guide, which is then adjusted until the blade edge coincides with the bend line. The guide is then locked in this position and the handle attached to the back of the blade is pulled over, this having the action of pulling the edge over, while the roller rolls the body of the work over the edge which is held in the slot.

As the blade is returned to its original position the work is taken with it and may now be removed from the slot with a perfectly parallel folded edge. It is the most rapid method of folding edges up to approximately 1 in. (the maximum capacity), for work such as folded edges, finish folds for grooved joints, and small wiring (10 gauge or less).

Right-angle Bender or Bending Press

As the name implies, this machine is used only for bending right angles, and consists of a heavy frame mounted on either a stand or bench, with a top arm which slides up and down between guides situated at each side. The arm is operated with an eccentric cam and hand lever (see Fig. 5).

The bed consists of a series of blocks, varying in length, so that they

can be built up as required to make a block of any desired length, to fit between reverse bends. These are located on the bed with dowels and have a vee-shaped groove running through them, in which the metal is bent. The top blade has a vee-shaped edge to fit the groove in the blocks, over which it is set absolutely central. The action of pulling the lever is to press the vee of the top blade into the vee of the blocks, thus forcing the metal between them to assume a right angle.

When the machine is used for boxwork, the two long sides are first bent into a channel shape and a top tool that will just fit between the sides is used in place of the full-length blade, as it is necessary for the sides to have clearance on both sides of the top tool. A guide is provided at the rear of the machine for setting the distance between the edge of the metal and the centre line of the bend, for use on repetition work. When only one article is required, a line can be marked to show the position of the bend, although a small centre-punch mark at each end of the line will help to ensure greater accuracy as the line is obscured when the top tool is lowered.

Power-driven Machines

Power-driven machines of this type, having one-piece blades and blocks, are made to deal with sheets up to 12 ft. long by $\frac{3}{16}$ in. thick, the method of operation resembling the power press, to which it is closely related. Bending in the press is done with tools of similar form, i.e. the bottom tool is a block with a vee of the required angle and radius machine in it, and the top tool is a blade of the same shape as the vee in the bottom block, but slightly smaller to allow for the thickness of metal to be bent.

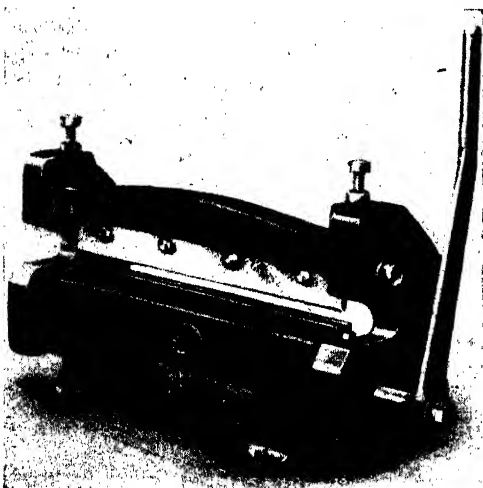


Fig. 5.—RIGHT-ANGLE BENDER

Bending Rollers

Bending rollers are used for bending sheet metal to curves of any desired radius, and for bending cylindrical work. Hand-operated rollers are made in sizes from 12 in. wide (for 20-gauge metal) to 4 ft. (for 16-gauge metal), their construction and operation being as follows: Two rollers, geared together, feed the metal past a third roller fixed behind them, so deflecting it to the required

radius. The feed rollers (i.e. the pair geared together) are adjustable, and should be set so that the metal can be just slipped between them when they are stationary, so avoiding stretching the edges and distorting the work, a fault which occurs when the rollers grip too tightly. The rear roller is adjusted with two hand-screws which raise or lower it to give the desired curve to the metal when it is rolled through.

To avoid forming a "flat" on the edge of the sheet remaining between the feed and bending roller, the sheet should be fed in until the edge reaches the rear roller and then the direction of rotation should be reversed, pressure being applied at the same time with the hand to the top of the sheet. This "sets" the end of the sheet to follow around the rear roller, so avoiding a break in the curve. A slip roller is fitted to some machines to facilitate the removal of closed cylinders by sliding them off the end of the roller.

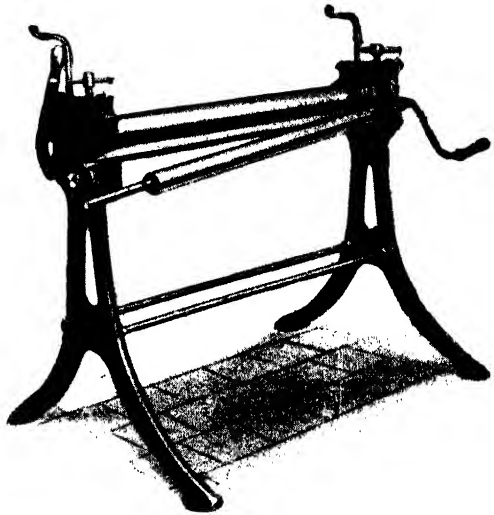


Fig. 6.—BENDING ROLLERS, SHOWING SLIP ROLLER OPEN

(*F. J. Edwards, Ltd.*)

Bending Jig

A bending jig is used when the shape in the panel is too full to safely permit rolling; this is usually made from sheet metal, long enough to extend past the ends of the panel, and shaped as in *Fig. 7*. The edge of the panel is slipped into the slot formed by bending up the bottom edge of the jig and setting is done by pulling over the shaped portion by hand.

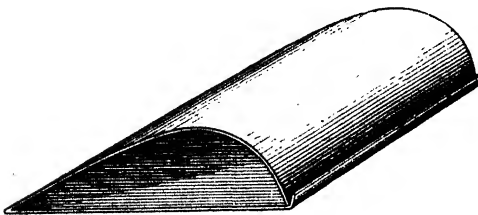


Fig. 7.—BENDING JIG FOR SHAPED PANELS

Another method of producing radiused bends is by the use of a length of suitable round pipe attached to the bench by clips. The metal is pulled round the pipe by hand, using a piece of flat board behind it to keep an even pressure along the bend, thus producing a perfect bend of the same diameter as the pipe.

Chapter V

WHEELING, BEADING, AND SWAGING

WHHEELING machines are one of the most useful tools to be found in the sheet-metal trade, and are indispensable where metal has to be beaten and shaped under commercial conditions. Wheeling is the smoothing of sheet-metal panels with steel wheels after the panels have been roughly beaten to shape. These machines are manufactured in a variety of sizes, and often vary in design for special classes of work, but the majority conform with the standard type illustrated in Fig. 1.

Standard Wheeling Machines

The framework is made from cast iron, and consists of two parts: *A*, the main frame, and *B*, the base or trestle. Between the frame is a steel shaft *C*, running in roller or bronze bearings *D*, to which is attached a flanged roller *E*, the whole of which is kept in position by a collar and grub screw *F*. Usually this roller has a flat working face, but some panel beaters prefer it to be slightly convex. Immediately under roller *E* is fixed a perpendicular pillar *G*, carrying a detachable roller, of which three different shapes are usually supplied with the machine (Fig. 1). The rollers are made of steel, the centres being bored out and the ends recessed to hold ball races, and through the centre is fixed a steel spindle which, projecting from either side, is used to suspend the detachable roller in the carrier *H*, parallel to the fixed roller *E*.

When the machine is in operation it is necessary to adjust the distance between the rollers to suit varying thicknesses of sheets, this being done by raising the pillar *G*. In the case of steel panels considerable pressure is required, so the screwed shaft *I*, fitted with a flanged wheel *J*, is provided, enabling the whole component to be raised or lowered during operation by turning the wheel with the foot.

On the shaft *C* is a handle *K*, which, while quite free from the rotation of the shaft, can, when necessary, be tightened and used to rotate the wheel *E*, this being required when wheeling work of small dimensions.

Modern Types

Modern types of wheeling machines have in some cases taken an entirely different form, although the principle is unchanged. Some machines are made in pairs, arranged back to back on a common bed,

thus saving considerable floor space. Again, in some works the machines are made from angle iron and bolted to the upright girders which form part of the construction of most workshops.

Many wheeling machines are now fitted with quick-release screws, making it unnecessary to unscrew part *J* when a roller is to be changed. It has also been found that when certain articles, such as motor-car rear mudguards and aero-engine cowlings, are to be wheeled there is not sufficient clearance underneath the machine. This has led to the introduction of a slightly different model (Fig. 2) for use with this special class of work.

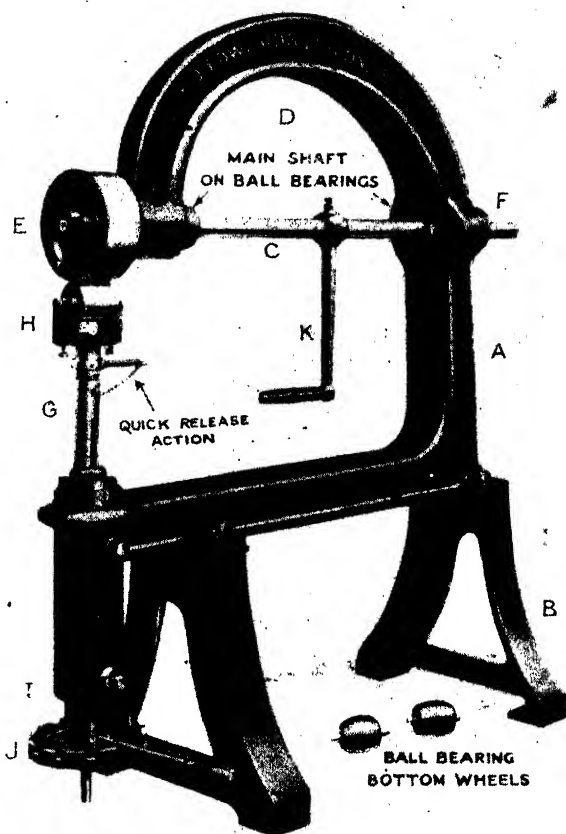


Fig. 1.—STANDARD TYPE OF WHEELING MACHINE
(F. J. Edwards, Ltd.)

Hints on Using

Many months of continual practice are necessary to become proficient in the use of wheeling machines, as so much depends on acquiring the "feel" of the work as it passes to and fro between the rollers. The work is first beaten until it is approximately the required shape, and is then slipped between the two rollers, being pulled backwards and forwards until all the mallet marks are removed.

The main difficulty experienced by the apprentice is the inability to keep the work in its original shape, and, unless the correct technique is used the article very soon becomes distorted. This continual loss of shape can be counteracted by the skilled operator by varying his movements, which become more or less automatic after practice, and work can be carried out with a speed and surface finish only excelled by press work.

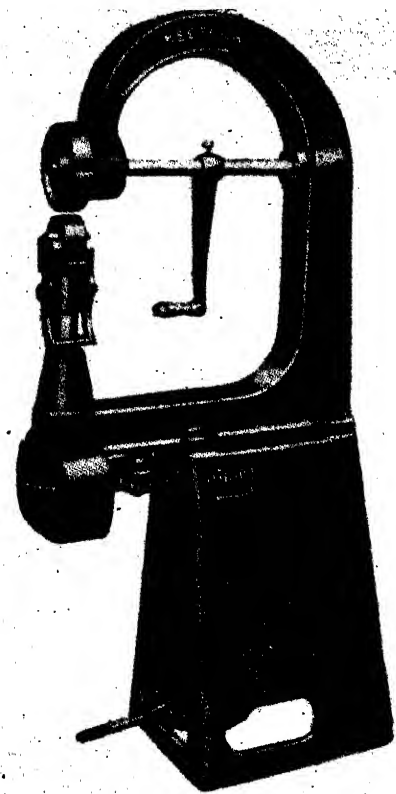


Fig. 2. SPECIAL WHEELING MACHINE
WITH EXTRA CLEARANCE

Increased Employment of Shaped Metal Sheet

Automobiles, railway engines, ships, and aircraft are all now streamlined, and as this necessitates the shaping of metal into curves to conform to aerodynamic standards and formulæ, very few straight or flat pieces of metal are now to be encountered in modern practice.

In motor construction the pieces of shaped metal are known as panels and are welded together to form larger sections. These are known in the aircraft industry as cowlings, but owing to rigid inspection at regular intervals the sections are kept fairly small, so that they can be easily detached.

Production of an Automobile Dome

The top part of a car is known as a dome, and to get this into the correct shape from flat pieces of metal it is necessary to beat the shape into the panels with a mallet until the correct contour is roughly obtained. After this stage the panel is made smoother by beating it between a mallet and shaped block of steel known as a

“panel head.” The next operation consists of finally finishing the panel on a wheeling machine by placing it between the top and bottom rollers and pushing and pulling it backwards and forwards until all dents or hollow places are smoothed away.

When wheeling, pressure is applied as required by raising the lower roller. If the contour of the panel requires raising, the bottom roller is raised, forcing the work against the top roller, and after a few passes through the wheel the necessary raising will be accomplished. The panel should not be gripped too tightly and the hands should allow it to follow its own shape around the wheel.

From time to time it will be necessary to change the bottom roller to accommodate whatever shape is being formed, using the straightest wheel possible without rubbing the panel or causing flat places. It is very important that each backward and forward movement should be accompanied by alteration of direction, so that the rollers make contact with

the panel in a different place at each movement (Fig. 3), at the same time making certain of covering the entire surface with the narrow track of the bottom wheel.

Wheeling Flat Panels

Flat panels or pieces of metal with little shape require the very minimum of pressure and should be brought to the required shape as gently as possible, avoiding all undue pushing and pulling, otherwise a fault known as "corrugating" will be produced. This fault is not easily corrected by wheeling, as this has a tendency to make matters worse, and usually the only remedy is to reset the panel, by again using the hammer and "panel head." In some cases the corrugations can be removed by wheeling the panel diagonally across the wheel tracks responsible for the fault (Fig. 5).

Varying Contours

The contour of automobile door panels, and also certain aircraft cowlings, vary from one point to another, with the result that the curve is greater in certain places. In order to obtain this variation it is necessary to run the wheel over the full parts more often than the surrounding places. As can be seen from the diagram in Fig. 6 the wheel is started in the spot where the fullness occurs, and after traversing to the bottom of the panel, the return is made over the same area already covered. The movement is continued to the top end, and in doing so the full place is wheeled twice the amount of the other portions, and to give a good surface finish it is customary to wheel lightly across the panel in a diagonal direction as shown in Fig. 6.

It will be found that panels with plenty of contour or curves can be subjected to considerably greater wheeling pressure without danger of corrugating the surface.

Correcting Mistakes

Sometimes too much shape is wheeled into a panel, providing a faulty general appearance when joined to other sections. This unnecessary shape can be removed by turning the panel upside down and wheeling the outside edges, or in the case of door panels this reverse wheeling can be carried through the entire panel.

When wheeling large work an assistant may be required to hold one side of the panel, and in this case care should be

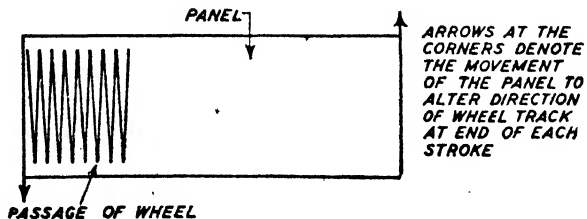


Fig. 3.—THE CORRECT METHOD OF WHEELING

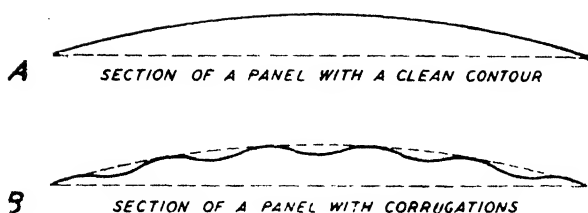


Fig. 4.—B SHOWS PANEL WITH FAULT KNOWN AS CORRUGATING

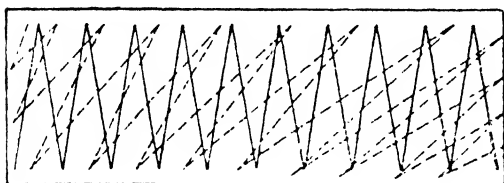


Fig. 5.—CORRECTING CORRUGATED WORK

Full lines denote path of original wheel track, and dotted lines denote diagonal path of correcting wheel track.

that the raising of shape is done evenly and not by a series of lumps.

Other Uses for Wheeling Machines

Wheeling machines can be used for other purposes than that of smoothing sheet metal, and in workshops where automobile mudguards are made by hand (i.e. instead of pressing) it will be found that the wheel is used as a rotary press. Hand-made wings (or mudguards) are composed of sections welded together, the sections consisting of the valence forming the sides, and the main body consisting of the top and, in the case of front wings, an apron acting as an inside shield.

All the parts are beaten to their required shape and after being wheeled smooth are welded together. During this latter process the metal has a tendency to warp and corrugate for a distance of approximately 2 in. on either side of the weld, owing to the uneven

taken to avoid roughness when pulling or pushing, as this will cause corrugation and unevenness of shape. The rule to remember when two operators are working on one panel is that each man should do his own

pulling, but on no account should he push the panel as it passes from him.

When wheeling panels of a very full shape the passage of the wheel over the work should be controlled so that the starting and finishing point of each stroke does not occur in the same position, the panel being moved so

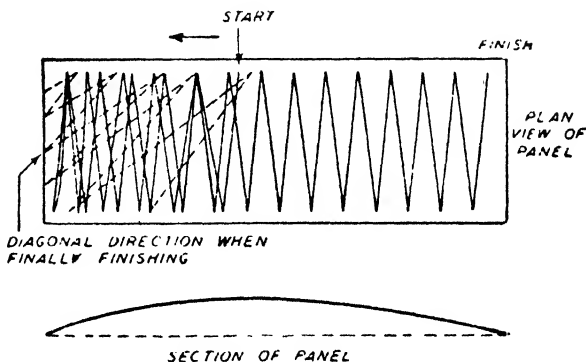


Fig. 6.—WHEELING A PANEL WITH A VARYING CONTOUR

heating and contraction. To remove these corrugations by hand-beating is a long and tedious job, so to obtain quicker production the two wheels of a wheeling machine are made to a standard shape (Fig. 1) and are known as Van-der-Plas wheels.

The handle inside the frame is removed and fastened to the portion of the shaft protruding outside the rear of the frame, so that by turning the handle the top wheel can be rotated. Thus if the wing is placed between the wheels and the lower wheel is tightened, it can be passed between the rollers by turning the handle, two or three passes usually being sufficient to again produce a smooth and regular surface.

Swaging with a Wheeling Machine

It may be noticed on modern cars that ornamental mouldings or swaging is used to improve the external appearance, and where cars are produced by hand this work is often done with the aid of a wheeling machine. Large panels cannot be swaged by ordinary swaging machines, owing to the lack of sufficient clearance between the back of the machine and the swage wheels, but by fitting wheels, shaped to the required form, into a wheeling machine, panels can be swaged to any design.

Denterazer Machines

A machine known as a Denterazer is to be found in many motor-body repair shops for smoothing out dents and hollows in bodies. In principle this machine is very similar to a wheeling machine, but is considerably smaller, and, instead of pushing the metal through the rollers, the machine itself is pushed and pulled over the work (Fig. 7).

The value of this can be appreciated for repair work, where, instead of having to dismantle the damaged portion the Denterazer can be run over the surface with a considerable saving of time and expense. To obtain good results it is necessary to roughly beat out the dents with a mallet and to remove all dirt from both inside and outside the damaged panel or wing, afterwards using the machine to provide a final smooth surface.

Sometimes the Denterazer is used as an ordinary standard wheeling machine for small work, by gripping one arm in a vice and passing the metal through the wheels in the usual manner:

BEADING AND SWAGING

Swaging is the operation used to raise up

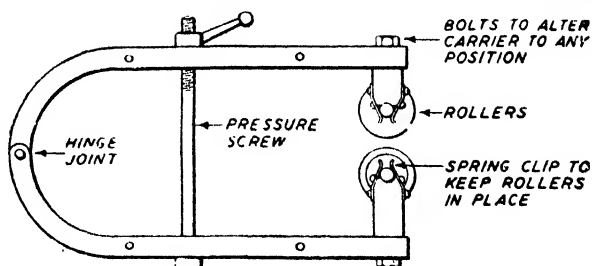


Fig. 7.—THE DENTERAZER MACHINE

moulding or beading on the surface of sheet metal used for motor-car bodies and similar work. This operation consists of forming the projections from the actual panel to be used on the body, etc., and is distinct from applied moulding where the form is made in solid metal, which is afterwards fastened on to the panels. Various methods are used to obtain these mouldings, but the most general method is to use a swaging machine fitted with suitable wheels.

The swaging machine (Fig. 8) consists essentially of a pair of shafts geared together and mounted in a suitable frame. Attached to one end of the shafts are rollers, male and female, shaped to produce a swage of the desired form. The top section of the frame, carrying the upper wheel and shaft, is hinged at the back and kept in upward tension by a flat spring. Vertical adjustment is provided to bring the wheels into mesh, and is operated with a small handscrew bearing on to the top arm. A small lever situated near the spur gears provides, through a face cam, for lateral adjustment, so that the wheels can be set to match up exactly when separated by the thickness of the panel.

An adjustable guide is provided to ensure that the swaged impression will be true and parallel with the edge of the panel ; that the impression will be symmetrical ; and, thirdly, to ensure that for repetition work all the mouldings, etc., will be uniform.

Setting Up and Use of Swaging Machines

Swaging machines are usually supplied with a considerable number of wheels, suitable for forming beads of various widths and mouldings of various sections. Some machines are also supplied with wheels for slitting (to convert the machine to slitting shears) and wiring. To set up the machine for operation it is necessary to select a suitable pair of wheels to give the required section, and fit the male wheel on the top shaft and the female on the other, locating them with the keys fitted in the shafts and locking them in position with the recessed nuts, which are screwed with right- and left-hand threads so that they will tend to tighten during use, instead of working loose.

Having fitted the wheels, they are " lined up " by slackening the locking screw and adjusting the small lever at the rear of the frame until the wheels engage centrally with each other. It is important to bear in mind when selecting the wheels that there will be a thickness of metal separating them when in use, and sufficient clearance must be allowed, otherwise the wheels will mark the side of the moulding and be prevented from engaging to their full depth.

Next set the stop to the distance required between the centre of the moulding and the edge of the sheet. Adjust the top screw until the wheel forms a depression in the metal and then run it through the wheels ; give another half-turn on the handscrew and repeat the operation until the

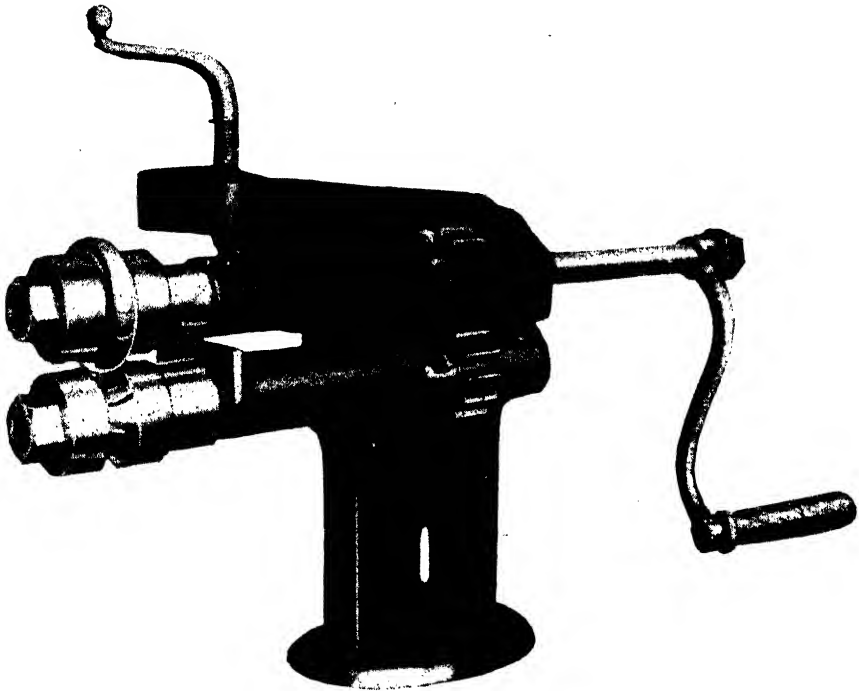


Fig. 8.—TYPICAL SWAGING MACHINE

wheel “bottoms,” at which stage the swage will be fully formed. The object of forming the swage in gradual stages (usually three to four passes through the wheel are desirable) is to draw the metal up gradually, thus avoiding strain, which may result in splitting or distorting the panel.

Care must be taken, especially on the first run, to see that the edge is bearing on the guide and, due to the fact that the metal is drawn in from the sides during the swaging operation, the back edge only will make contact with the guide in subsequent runs, but this will be sufficient to keep the job true with the wheels.

Where heavy work has to be handled it is advantageous to have a metal-covered table alongside the machine, with the surface at the same height as the wheel centres, to take up the weight of the job. The operator can then feed the sheet through the wheels while an assistant

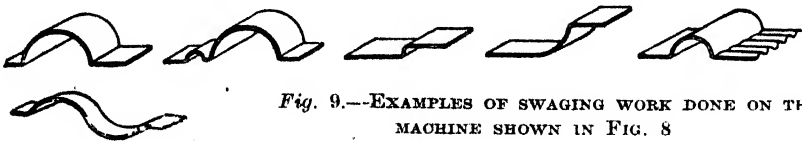


Fig. 9.—EXAMPLES OF SWAGING WORK DONE ON THE MACHINE SHOWN IN FIG. 8

turns the handle. Where such an accessory is available it is only necessary to hold the sheet lightly on the table with the palm of the hand while the sheet slips under the hand, thus creating sufficient friction to keep the edge bearing on the back of the guide.

Uses for Swaging

Swages are used for a variety of purposes in sheet-metal work, such as decoration, stiffening section and forming stops, shoulders, and rebates. Large flat panels, which are apt to be "floppy," are sometimes stiffened by running a half-round swage around the edges, this particular shape of section giving considerable extra lateral strength. Loose panels (i.e. panels which have been distorted by stretching in rollers or some other operation) can be tightened by swaging as the looseness is taken up in the extra metal required in the swage, and the neat half-round section adds to, rather than detracts from, the general appearance.

Large flat areas on some parts of motor-cars and coaches (e.g. the bottom of the foot well and running boards, floor and seat walls) are frequently swaged to give additional strength and to prevent "drumming" when the completed car is running on the road. Examples of the combination of strength with decoration by swaging is to be found in the design of circular articles, such as drums, dustbins, baths, etc. Swages are frequently used for location purposes on tanks, and on some aircraft tanks are used to form a channel to locate the holding-down straps; two swages, an exact distance apart, being used in this instance (Fig. 10). A swage, run around the top of a box or canister, is frequently used to act as a stop for the lid and to strengthen the top rim (Fig. 10).

Where the swage or bead is required to be on the extreme edge (as on a number plate, etc.), the metal should be swaged a short distance in from the side and the surplus trimmed off on the guillotine to form a clean edge (Fig. 11). The side panels of a motor coach usually have a double swage running through them; the metal between the swages being painted in a contrasting colour to give the effect of a separate panel, which is often used as a background for lettering (proprietor's name, 'bus destinations, etc.). The profile giving the positions of these swages is shown on a board and the whole set of panels is run through the wheels at the same setting to ensure uniformity.

Decoration for Cars

The swage is a very important part of the decoration of a car, and great attention is usually given to its use. Starting at the bonnet or dash, the swage is carried through the doors and around the back in one continuous sweep, thus forming the waistline of the car. It may take many forms, but a general design for saloon cars is a moulding of the form shown in Fig. 13, A.

Arrowhead Moulding

On some coupé and sports models the moulding is made to separate at the rear; one part passing around the waist rail and the other following on to the tail. Another style of moulding in vogue is the arrowhead type, which starts at the dash as a narrow moulding about $\frac{3}{4}$ in. wide, widening as it follows an easy sweep to the back, and then terminating in a spearpoint (Fig. 13, B).

The moulding on a car is first "set" by the bodymaker, who makes a wooden moulding of the required shape and fixes it in the correct position. The panel beater makes his panel and after smoothing in the wheeling machine, temporarily fixes it into position with panel-pins or cramps, and "marks off" the position of the moulding with a long bent scriber, the end of which rests on the wooden moulding which forms a guide while the scriber point marks out the exact shape and position on the panel as it is drawn along the moulding.

If the moulding is parallel, the marking may be dispensed with and the guide on the swaging machine used in its place, but curved and tapered mouldings must be formed freehand, by guiding the panel through the swage wheels on the line marked off by the previously described method.

For this work single-sided wheels are used (Fig. 15) so that the swage may be formed up, one side at a time (Fig. 14); or several wheels may be "ganged" together with suitable thickness packing washers between them to form a flat-topped moulding of any desired width (Fig. 16).

Swaging Round Back Corners of Car Bodies

When swaging round the back corners of car bodies, the moulding has to stand out from the panel and therefore make a bigger sweep, which means that the outside of the moulding will be longer than the metal from which it was formed, and must therefore be stretched during operation. This stretching can be done with the wheels, but this is an undesirable method, as the wheels

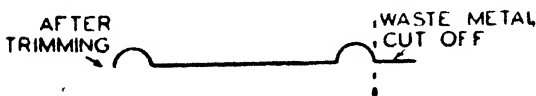


Fig. 11.—A SWAGED EDGE

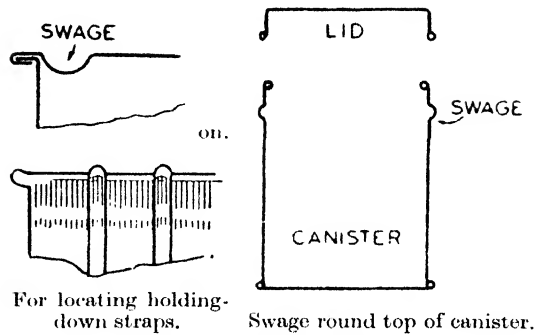


Fig. 10.—USES FOR SWAGING

also pull the panel inwards at the points immediately below the swage. Although the resulting effect is not very

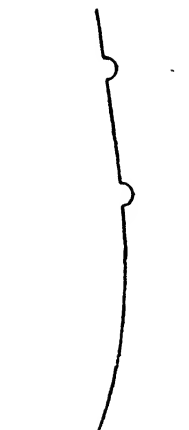


Fig. 12.—SWAGED
SIDE PANEL OF A
COACH

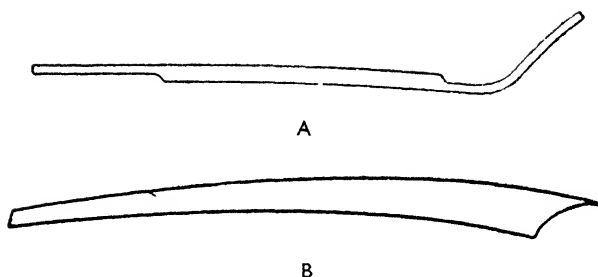


Fig. 13.—TYPICAL CAR-BODY SWAGES

unsightly, it is undesirable, as the panel is prevented from “seating” properly, thus causing it to fit incorrectly to the other panels. To avoid this the panel is stretched by beating it between a sandbag and studding hammer to give the necessary increase in area between the swage lines, and the wheels are then

able to form up the moulding without disturbing the metal on either side of it (Fig. 17).

If the moulding is “swept,” i.e. curved, but at the same time is parallel and the edge of the panel straight (as in the case of door panels), the swage guide may be used if a piece of scrap material cut out to the desired shape is fastened on with screws or rivets to act as a template. Thus by pushing the panel so that the template is always in contact with the guide, a considerably cleaner contour is obtained than if the work was done freehand. When a swaged panel is mounted on the car the wooden moulding should fit inside the swage and, when all the swaged panels are assembled, should appear as a continuous moulding. Any breaks which may then be apparent are trued up by the use of hand chasers.

Composite Swaging

Where a moulding is required of extra width or of more artistic shape than those formed by standard wheels, it may be built up by using two or more pairs of wheels separately, some typical examples being illustrated in Fig. 18. Care must be exercised when making these swages to form them in such order that the wheels for one part of the swage do not foul the parts already formed.

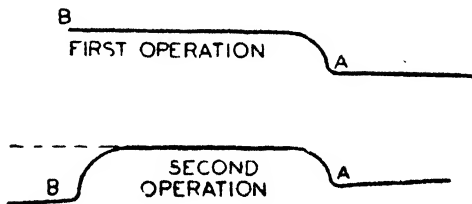


Fig. 14.—FORMING CURVED AND TAPERED
MOULDINGS

Swaging Tubes and Pipes

Tubes and pipes that are to be joined by means of rubber hose and clips are swaged at their ends to make a water-tight joint and to prevent the hose from pulling off. These pipes are usually too small to be swaged in the standard machine (as the wheel would have to fit inside the pipe), so it is necessary to use a tool known as a hand swage. This consists of a solid mandrel (with the shape of the swage turned on to the

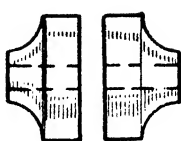
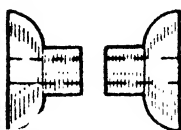


Fig. 15. SINGLE-SIDED WHEELS FOR FORMING CURVED AND TAPERED MOULDINGS



Fig. 16. SINGLE-SIDED WHEELS GANGED TO FORM A WIDE PARALLEL MOULDING



outside surface), and a top tool, similar to a grooving punch with a female impression, mounted over it in a slide or on a pivoted arm; the whole being mounted in a suitable frame (Fig. 19). The pipe is slipped over the mandrel, up to the stop, and the punch is tapped with a hammer whilst at the same time the pipe is rotated by hand, the whole device being usually held in a vice. The pipe is held vertically with the left hand while the punch is struck with a hammer, the pipe being rotated slowly until the swage has been completely formed.

Forming Moulding in a Cramp Folder

It may be required to form a wide moulding for which wheels are not available. Such mouldings may be formed, one bend at a time, by working from either side on a cramp folder, of which some typical examples are shown in Fig. 20. These sections are used for strength rather than appearance, and are often made separately and riveted to flat sheets to act as stiffeners or runner.

Sometimes it is necessary to swage very large work, or work whose difficult shape prevents the use of standard machines, owing to the limited

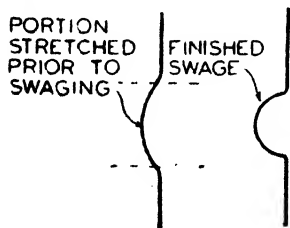


Fig. 17. SWAGING ROUND BACK CORNERS OF CAR BODIES

clearance between the shafts. Such work includes motor wings of helmet section (Fig. 21), which requires a considerable amount of clearance on either side as it passes through the rollers. This difficulty can be overcome by replacing the normal wheels on a wheeling machine with swaging wheels (which usually have to be made specially) and rotating the shaft by means of the handle, which, for this purpose, is fixed to the end of the shafting

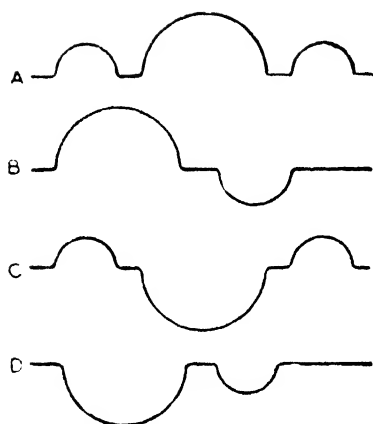


Fig. 18.—COMPOSITE SWAGING

projecting outside the frame (see section dealing with “Wheeling Machines”).

A guide cannot be used for this method, and the swage must be made freehand by working to a line, two operators being necessary to turn the handle and guide the work through the wheels. Due to the fact that the bottom wheel is supported on a pillar, there is almost unlimited clearance on either side, and despite the fact that only the top wheel is driven, a very satisfactory swage can be obtained.

Guttering, etc.

Guttering is made on a guttering press which is an adaptation of the right-angle bending machine, fitted with a top and bottom tool to give the required section when the tools come together, in a similar manner to an ordinary press. Moulding and guttering tools are frequently made to be interchangeable with the tools used for right-angle bending, to enable their use on this standard machine.

Drawn Sections

Moulding, in long lengths as used for shop fronts, etc., and the stiffening sections (Z shape) used for “stringers” and “stiffeners” in aircraft work, are produced on a draw-bench, which usually takes the form of two channel or girder sections mounted parallel to each other, so that a slot is formed between them. A head is fixed at one end to hold the dies or swage wheels, and a travelling cramp or vice, operated through a geared handwheel and endless chain, travels along the whole length of the bed.

The raw material consists of a strip or ribbon of metal which is threaded through the two halves of the forming die, and locked in the travelling cramp, which then draws the metal through the die, thus forming it to shape. The two halves of the die are adjustable and slightly tapered to

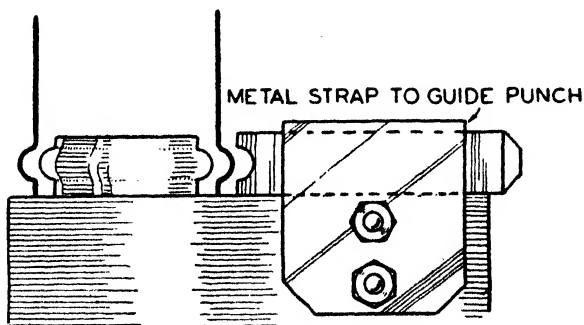


Fig. 19.—HAND SWAGE FOR PIPES

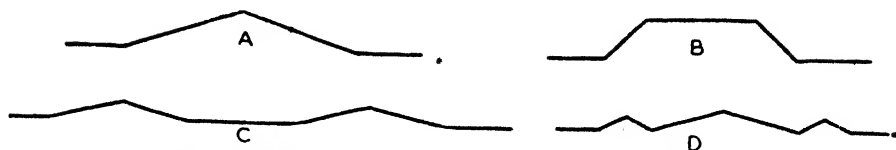


Fig. 20.---EXAMPLES OF MOULDING PRODUCED IN A CRAMP FOLDER

give a "lead" to the metal by roughly forming it to shape. It may be necessary to pass the material several times through the dies, starting with them slightly separated and then closing them a little for each successive run until they form the full shape. A heavy lubricant, such as bees-wax or soap, is necessary when using this type of die in order to reduce friction and prevent damage to the surface of the work.

A better method of producing moulding on a draw-bench, if the quantity is large enough to warrant the expense is to use a series of swage wheels mounted as a battery, each successive pair of wheels forming deeper than those preceding until, finally, the full section is obtained. By this method sections may be obtained in one "draw," although, of course, a single pair of wheels may

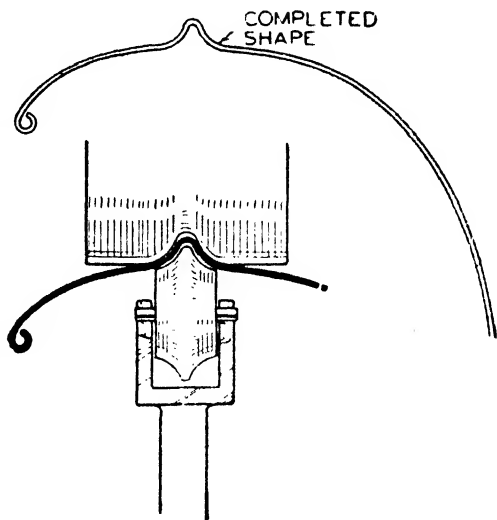


Fig. 21.—SWAGING IN A WHEELING MACHINE

be used, as in a swaging machine, by taking the metal through them several times, adjusting the wheels closer after each "draw" until the

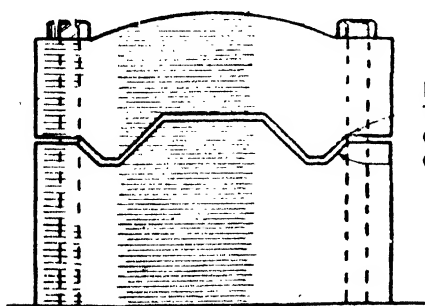


Fig. 22.—DIE FOR FORMING AIRCRAFT CHANNEL SECTIONS ON A DRAW BENCH

full depth is obtained. Sections formed on a draw-bench have a tendency to distort and twist, owing to the edges becoming stretched in the forming process. These may be straightened by fastening each end and exerting a pull which will tend to stretch the centre and so take up the slack material in the edges.

Chapter VI

MECHANICAL JOINTING, RIVETING AND SOLDERING

JOINTS and seams used in sheet-metal work may be classified as either mechanical joints (where the edges of the metal are bent to a self-locking form), riveted, or metallic joints (soldering, brazing, and welding).

The most generally used form of mechanical joint is the grooved joint, which is made by folding the edges to be joined in opposite directions so that they hook together, then with a grooving punch (or "groover") the metal is set down to form the joint (Fig. 1). The groover has a half-round groove cut in its face, and when in use one side is held in contact with the open side of the seam, which acts as a guide, while the other side is set with light taps on the groover, at the same time as it is moved slowly along the seam. This should be repeated two or three times until the joint is flush on the inside. This joint is used extensively for tin work of all kinds, petrol tanks, cylinders, etc. When the joint is required to be flush on the outside, a sunk grooved joint is used, which is made by sinking the joint into a slot, such as a keyway in a shaft, or other suitable tool (Fig. 2).

Where the metal is too thin or thick or otherwise unsuitable for grooving (e.g. perforated gauze), a strip seam may be employed (Fig. 3), where the edges are folded and the strip introduced from the end.

For box corners, bottoms, or ends, the seam shown in Fig. 4 makes a neat and strong joint. This is made by turning a square edge on the end of one side and a fold on the other; these are engaged and then panned down and folded over, with a mallet or hammer, on a sharp-edged tool (e.g. the flat end of a mandrel).

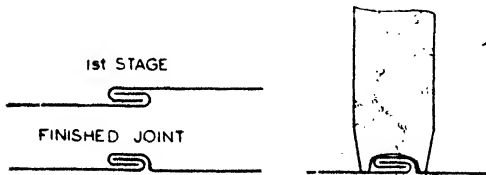


Fig. 1.—MAKING GROOVED JOINT

Right—showing how joint is accommodated in the grooves.

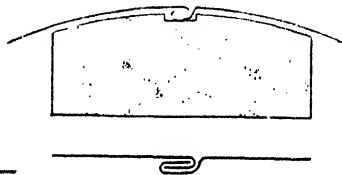


Fig. 2.—SUNK GROOVED JOINT

Bar with keyway for making grooved joints inside is shown at the top.

Fig. 5 shows a similar joint employed for seaming bottoms, and is known as a "knocked-up joint." This is made by turning a flange out square with the body and turning an edge up square with the bottom, so that it is an easy fit over the flange. This edge is then gently paned down on to the flange and the whole edge knocked up, over a sharp-edged round tool (e.g. the round end of the mandrel).

In workshops where this type of joint is extensively used, simple machines are employed which turn the flanges (a Jenny is used for this operation) and form the joint with specially designed wheels on machines known as "paning-down machines" and "bottom-closing (or knocking-up) machines" respectively.

Riveted Joints

For riveted seams a lap of at least three times the diameter of the rivets is required. The seam is made by drilling a hole through the pieces just large enough to clear the rivet, which is inserted from the inside and slipped on to a suitable tool. A draw set is then used to "draw" the rivet through the hole. A few taps with a hammer will "spread" the top of the rivet, which is then "snapped up" by positioning the button set or snap over the rivet and giving one or two blows with a hammer. If the rivets are too long they should be cut down to about one and half times the diameter of the rivet, which length should provide sufficient material to form a good snap head.

With snap-head rivets, a "dolly" is used under the rivet head, this being simply a suitable bar with a cup formed in it to fit the rivet head. Rivets are made with different-shaped heads and in various sizes (both length and diameter), and of metals to suit the material to be joined. Iron, copper, aluminium, Dural, brass, and stainless-steel rivets are made for use, and rivets of the same metal as those to be joined should be used. Where two dissimilar metals are to be joined a compromise must be made; thus copper rivets are frequently used for both iron and brass, and aluminium rivets for jobs where a very soft rivet is required. Tubular rivets are sometimes used for light structures on aircraft and are set by spreading the ends with a beelling punch or other suitable tool.

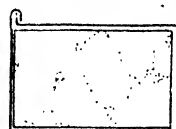
Where a joint is under shear strain and the rivet pitch required would be too close, a double staggered row of rivets is used.

Riveting—Using Dolly

When riveting is to be carried out *in situ*, as for aircraft construction, tanks, etc., it is necessary to use a "dolly" behind the rivet, against which it is hammered up. For flat-head and counter-sunk



Fig. 3.—STRIP JOINT



1st STAGE



FINISHED
JOINT

Fig. 4.—Box-
CORNER JOINT

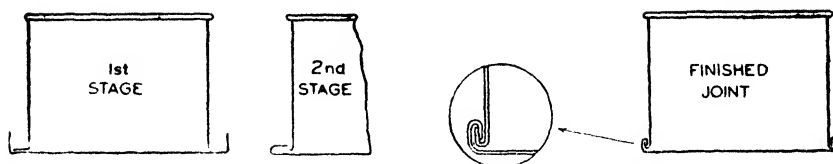


Fig. 5.—KNOCKED-UP BOTTOM JOINT

rivets this may be any flat block of steel or steel bar held endways against the rivet head, but for snap-head rivets a hemispherical depression must be made to accommodate the head and preserve the shape. This may be made by first drilling a “countersink” in the end of a suitable bar, heating to redness, and then using a punch and steel ball of the correct size, to complete the cup. For work entailing the use of a “dolly,” two operators work together, often out of sight of each other. The man on the inside of the job puts the rivet into the hole and holds the dolly against the head and then signals his partner that he is ready; the rivet is then cut and snapped up in the usual way with a rivet set or pneumatic riveting gun, if the latter is available.

Rivet Squeeze

A very useful tool for riveting aluminium and Dural fittings is the rivet squeeze, a tool resembling a bear punch, but with rivet cups fitted in place of the punch and die. This makes a neat and quick job when closing soft rivets, but its capacity is limited to the depth of the throat, which is usually 3 in. to 4 in.

Flush Finish

Riveted work on which a flush finish is required is obtained by using countersunk-head rivets, if the metal is thick enough to take the countersink, or on thin metal with flat-head rivets, using a recessed draw punch, the metal being drawn into a cup to accommodate the head without weakening it. Where fittings are to be flush riveted to sheet metal the best method is to countersink the fitting only, and use countersunk rivets. When drawn up in the usual way the head will pull the sheet up into the countersink in the form of a conical cup, thus preserving its strength.

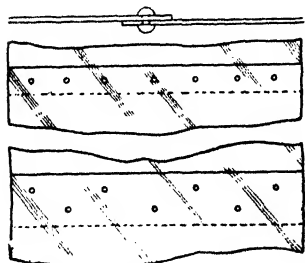


Fig. 6.—RIVETED SEAMS

Tinned-steel tanks are usually riveted with tinned-copper rivets and the joints and fittings sealed by “sweating” after riveting, Dural, of course, cannot be soldered, but is sealed by inserting jointing material between the laps before riveting.

SOLDER AND SOLDERING

The process of soldering is an amalgamation between two metals, the solder and the work, and it naturally follows that the surface of the work should be clean, as the solder will adhere only to metal, and not to a film of dirt, grease, or rust which may cover the metal. Soft solders are alloys of lead and tin in approximately the following proportions :

SOFT SOLDERS

—	Lead	Tin	Bismuth
Plumber solder	3	1	—
Tinman's (general purpose)	1	1	—
Tinman's (fine)	1	2	—
Pewterer's solder	1	1	2

Bismuth solder, which is used for pewter and other alloys having low melting temperatures, has a melting-point of only 203° F., less than the boiling-point of water.

Soldering Fluxes

When soldering, a flux is used to break down and float off oxide and other surface impurities and to prevent the formation of oxide by the heat. The most generally used flux is "killed spirits," made by dissolving as much zinc as possible in muriatic acid or spirits of salts (i.e. a saturated solution). This should be done in a wide-necked earthenware jar, in the open air. The jar should not be more than half-full, as the violent chemical action causes it to "boil up." When "killed" there should be some undissolved zinc still left at the bottom, and the liquid should be clear and colourless. This is used as a flux for copper, brass, iron, and tinplate.

Raw spirits of salts is used as a flux for zinc and galvanised iron.

Sal ammoniac is used when tinning iron, copper, brass, and cast iron, this being a very powerful flux, but is highly corrosive and must be thoroughly washed off after use.

Tallow is used as a flux for lead and plumbers' wiped joints, and resin is used as a flux for lead and electrical work where an acid flux must be avoided. Mixed together, tallow and resin make a useful paste flux.

Making a Soldered Joint

For an ordinary soldered joint, a lap joint of $\frac{1}{8}$ in. to $\frac{3}{8}$ in., according to the thickness of the



Fig. 7.—RIVETS

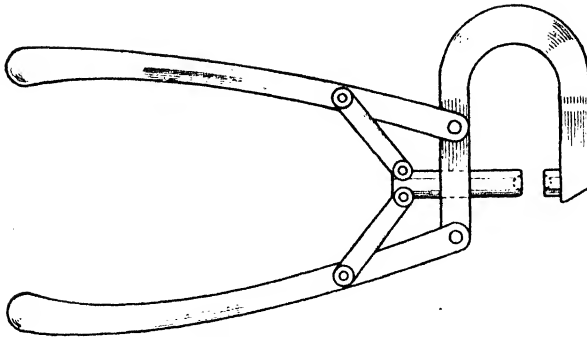


Fig. 8.—RIVET SQUEEZE

metal, is required. The joint is then fluxed and solder applied with a hot, well-tinned copper bit, with its edge in contact with the work.

As the copper bit is only a convenient reservoir of heat, it should be left in contact long enough to warm the work up to

the melting temperature of the solder, which will then be seen to spread over the surface of the metal. The bit should then be drawn along the joint, using the edge of the top lap as a guide, and fed with solder on the top face, from where it will run down into the joint. The solder will follow the copper bit, so it must not be allowed to wander off the joint or an unsightly smudge will be produced. The solder is fed on to the iron by dabbing the face from time to time with the stick of solder.

When the edge of the solder on the joint forms up into a ridge it is an indication that the bit is becoming too cool for further work and should be re-heated.

If, after heating, the bit "smokes," it is too hot for use and should be allowed to cool slightly, so that when dipped into flux the tinned faces remain bright. When a copper bit has been overheated so that the faces are burnt black, it must be cleaned up with a file, preferably while hot, and re-tinned by dipping into flux, applying solder, and rubbing on a piece of tinned metal.

As solder has very little mechanical strength, a soldered butt joint is unsatisfactory, due to the fact that the solder would have only the thickness of the metal to which to adhere. If a flush joint is required, a strip of metal should be "sweated" on from the back, this being known as a strap joint.

Sweated Joints

A "sweated" joint is a joint which is soldered through the whole surface of the two pieces in contact. Sheet-metal joints are usually "sweated" by applying the copper bit flat, on top of the joint, so that it is heated completely through, and solder will be seen to "sweat" out from the other side, thus indicating that the solder has penetrated right through the joint, soldering together the whole of the two surfaces in contact. Tank rivets may be neatly "sweated" from the outside by holding one face of the bit in contact with the rivet head only, and allowing the solder to flow down and around it, giving a perfect seal



Fig. 9.—A MODERN SHEET-METAL PRODUCT
Fixing an air fan to its sheet-metal case.



Fig. 10.—A MODERN SHEET-METAL PRODUCT
Lining up position for air fan. (By courtesy of Tecalemit, Ltd.)

and confining the solder to the vicinity of the rivet head, in a small neat ring.

In cases where the heat stored in a copper bit is inadequate, the surfaces which are to be sweated together are first "tinned" by coating with solder, then, after positioning the two pieces, heat is applied with a blowpipe until the surplus solder is seen to exude from the sides of the joint when pressed together. This joint, if not otherwise held in position, should be kept tightly pressed together until the solder sets.

Floating and Bridging

Floating and bridging are two methods of soldering which are very useful on certain classes of repair work, but it must be emphasised that these methods are not used for any aircraft work as they come more in the category of "faking" than of jointing. A hole which is to be filled with solder may be "floated" by laying the bit over the hole with its whole face in contact, and at the same time drawing it sideways, with both sides of the hole in contact with the face of the bit. The solder will spread in the form of a film across the hole and join up with the other side. Small holes may be filled by inserting the point of the bit into the hole, twisting it around and withdrawing vertically. "Bridging" a gap with solder is done by building up with solder from both sides, using a cool bit, until it joins. This can rarely be done neatly, and it is usually filed or scraped afterwards.

Silver-soldering

Silver solder is an alloy of copper, zinc, and silver, used mainly for joining brass and copper, borax being used as a flux, and the process produces a neat, strong joint. As the solder is fairly strong in itself, material of a suitable thickness may be butt joined, but in most cases sheet-metal joints are scarfed and lapped to give a larger area of contact. A scarfed joint is made by thinning the metal on one side to produce an acute angle, so that when the two scarfed edges are lapped, the total thickness is that of the single sheet. When two pieces are to be joined at an angle they may be propped into position and silver-soldered, the solder forming a fillet which will be of ample strength for most jobs.

To silver-solder a joint it is necessary to first lay the parts in position, and if required fasten the parts with fine binding wire, clamps, or weights. The flux, which is made by mixing borax and water to the thickness of cream, is next painted sparingly on to the work (this should be confined to the joint, as surplus flux is difficult to remove after it has been fused) and the joint heated with a blowpipe, or other convenient source of heat, until the flux fuses and runs into the joint. Next warm up the end of the silver solder and dip into flux. Continue heating the joint, stroking it from time to time with the end of the silver solder until it is

hot enough to melt off a little from the end, which will follow the flux and run into the joint.

Silver solder should be used sparingly both in the interests of neatness and economy, as it is fairly expensive. If necessary, more flux may be added and the flow assisted by using a spatula made by flattening the end of a piece of wire with a hammer. After cooling, the flux (which is now like glass) must be removed by chipping or filing and the joint cleaned up.

Silver solder is usually supplied in the form of ribbon, which is then cut into thin strips and mounted in a suitable holder to eliminate waste.

Brazing

The process of brazing is similar to silver-soldering, except that brazing wire is used for joining material and a rather higher temperature is required. This is used for joining copper and steel. Brazing spelter is sometimes used in place of brazing wire, this being a mixture of granulated brass and borax, which is sprinkled on the joint, and then heated until the spelter fuses. Where an extra strong joint is required, the edges to be joined are scarfed and a series of cuts made in one edge, dovetail fashion. These cramps are then bent alternately up and down, the plain scarfed edge inserted, and the whole joint hammered up tight. This is then loosened a little by tapping the end of the joint edgewise with a hammer, so that the brass may flow between the cramps and the scarfed edge.

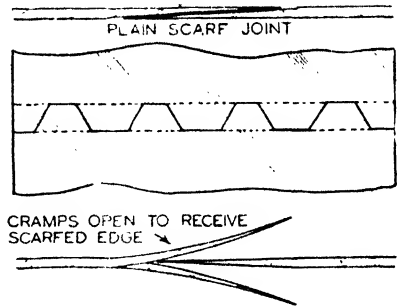


Fig. 11.---CRAMPED JOINT FOR BRAZING

Chapter VII

WELDING SHEET METAL

OXY-ACETYLENE and electric resistance welding are today playing an increasingly important part in the fabrication of sheet-metal work. Many difficulties have had to be overcome before the various welding processes could be successfully applied to the welding of thin sheets of iron, steel, aluminium and copper—the chief materials used by the worker in sheet metals.

One of the chief difficulties was due to the fact that metal in the form of light gauge sheets has a lower heat conductivity, owing to the small cross section of metal which is available for conveying heat away from the joint which is being welded. This fact was the reason for many failures in sheet-metal welding, owing to the burning of the metal. The methods described below show how this and other difficulties have been overcome in practice.

Fusion welding with an oxy-acetylene flame is a process by which the edges of the pieces to be joined are melted and run together, fresh metal being added, to make up losses and gaps, by means of a filler-rod of the same composition as the metal to be welded.

IRON AND MILD STEEL

Iron and mild steel are the easiest welding metals. Flux is not required, but care and experience are necessary to produce a good neat joint. The most general method is to "tack" the edges together by melting them together at intervals of approximately 1 in. The joint is then hammered on a suitable tool to bring the edges into perfect alignment. The flame is then directed along the weld, from right to left, at an angle of about 30° and set so that the cone is about $\frac{1}{8}$ in. from the joint; then, with a small circular motion of the blowpipe, a little pool is melted and run together. The left side of the pool is constantly being melted down as welding continues and the metal runs behind the flame and cools, giving the familiar herring-bone pattern. Care must be taken to keep the flame moving or the metal will be melted and collapse through the back, leaving a hole which will have to be filled up with filler-rod, and producing an unsightly lump.

For making corner joints when the sheets of mild steel have to be welded at right angles, the free edge method will be found useful. No welding rod is required (Figs. 1, 2 and 3).

Place one of the sheets flat on the welding table, with the edge of the sheet to be welded overhanging the table edge a distance of 2 or 3 in.

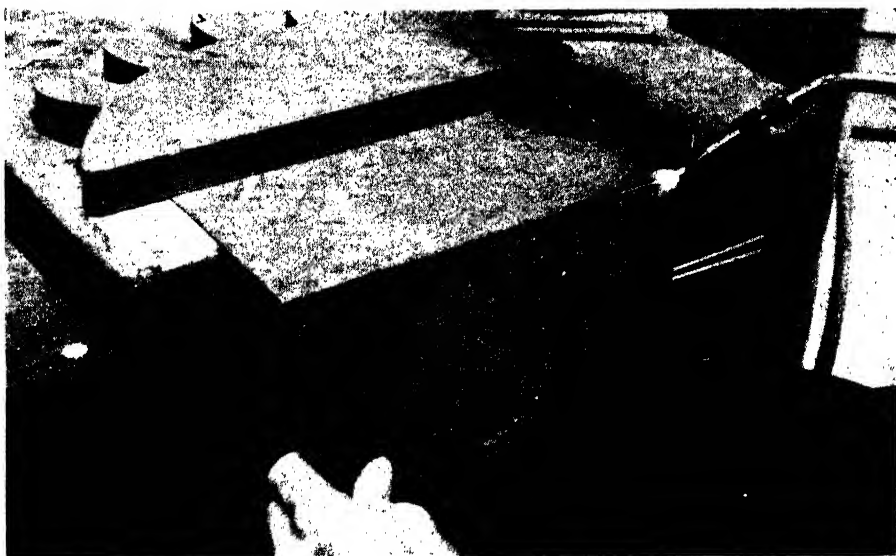


Fig. 1.—HOLDING AND TACKING PLATES FOR FREE EDGE WELDING WITHOUT FILLER ROD
Note taper spacing which is controlled by the operator.



Fig. 2.—FREE EDGE WELD IN PROCESS
Note how the plates are drawing together, due to expansion. (*British Oxygen Co. Ltd.*)

Place a substantial weight on the other end so that the sheet is securely held down on the table.

Then take the other sheet in the left hand and the blowpipe in the right hand. Place the right-hand corner of the metal against the corresponding corner of the other sheet. Do not bring the two edges close together along the remainder of the length, but leave a taper space between them corresponding to the expansion that will take place. The allowance for expansion of mild steel is about $\frac{1}{4}$ in. for every foot of length. The welder should adjust the taper space to this allowance, remembering that in this case expansion is in two planes, horizontal and vertical, not as in the case of butt welds, along the horizontal plane alone. Therefore, hold the left end of the sheet away from and below the horizontal sheet.

Now apply the flame to the right-hand corner and tack the two sheets together by melting the edges. Proceed to melt from right to left. The two edges will draw together owing to expansion. The correct angle of the blowpipe is shown in Fig. 3.

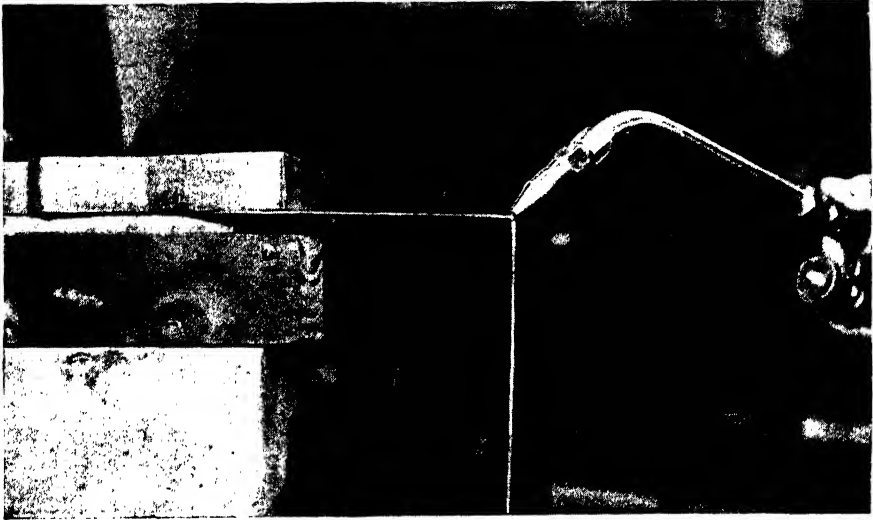
When welding the heat is rapidly conducted throughout the metal and has the effect of upsetting the metal adjacent to the joint. If this excess heat could be absorbed in some way, the amount of distortion would be considerably lessened. Such a desirable effect can be achieved by placing metal or other conductors around the weld so that they will absorb the heat from the metal and dissipate it to the air. In this way the heat put into the job is confined to the line of the weld, and the weld can be done without setting the edges of the sheets to a taper spacing.

The materials employed to conduct heat away from the job are known as "chills."

Figs. 4 to 7 show a simple jig applied to a sheet-metal butt weld, which serves to hold the job in place, as well as to prevent distortion of the sheet metal and to absorb and dissipate the heat from the job. The jig consists first of a steel base plate with a groove down the centre. This is placed on the welding table. The two sheets to be welded are arranged on this, so that the joint comes directly over the groove, and then two other plates with bevelled edges are set, one on each side of the joint. The whole is then clamped together with four cramps, as shown in Fig. 7.

Fig. 8 shows a suitable jig for welding corners in sheet metal, such as in the welding of rectangular vessels. As will be seen, it fulfils the same purposes as described in connection with the butt weld jig.

It will be evident that the method of avoiding distortion outlined above can be applied to a variety of work. Fig. 9 shows an example in the welding of a drum made of 18/22 S.W.G. steel. Two pieces of $\frac{1}{4}$ -in. steel are placed along the line of the weld and another piece of steel placed



*Fig. 3.—END VIEW OF COMPLETED FREE EDGE WELD
Showing correct angle of blowpipe. (British Oxygen Co. Ltd.)*

on the underside along the length of the weld and the whole clamped together.

Water can also be used in many cases for dissipating the heat. The manner of its use, of course, depends upon the particular job being welded. In some cases it is possible to rig up a hose to distribute the water evenly over the parts affected. An example of its use in this way is shown in Fig. 10, in connection with the seam welding of cylinders for drums or tanks of thin gauge material. A length of iron tubing in which small holes have been drilled is bent to a U shape, and the two open ends caulked up. At the other end a flanged hole is made to take a piece of rubber tubing fixed to a water supply. During welding the water is turned on and is sprayed in jets over the drum, thus keeping the surface cool.

Water can often be placed inside a piece of work which is to be welded to another piece, thus dissipating the heat.

OXY-ACETYLENE WELDING OF ALUMINIUM

Welding is probably the most satisfactory method of joining aluminium, but this metal is somewhat more difficult to weld, owing to its low melting-point (which occurs at a temperature below that of visible red heat) and the rapid formation of oxide on the surface, which must be broken up by probing or stroking with a filler-rod coated with flux. Welding aluminium requires considerable practice, as it is more a matter of judgment and feel than of sight.

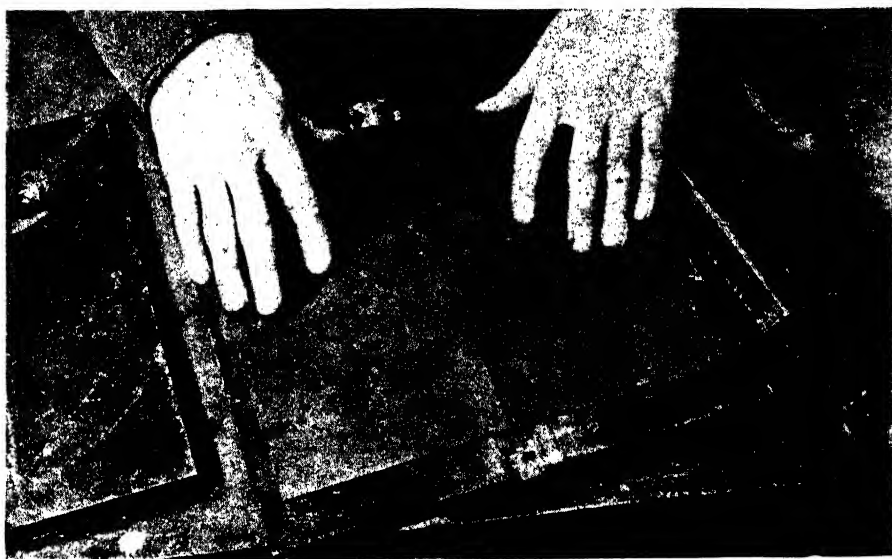


Fig. 4.—JIG FOR SHEET METAL BUTT WELD BEING ASSEMBLED
(British Oxygen Co. Ltd.)

Light-green goggles should be worn when welding this metal, so that the joint can be clearly seen, and the flame should be quickly lifted as soon as the surface appears to collapse (due to the formation of an under-bead of metal on the underside), at the same time probing with the filler-rod, to feed on the flux and add a little metal to the joint.

Of the many aluminium alloys marketed to-day, each has properties intended for specific purposes and involving its own problems of production and manipulation.

In the welding of aluminium and aluminium alloys by the oxy-acetylene blowpipe flame the first thing to be considered is the flux.

The Flux

In choosing and using a suitable flux two considerations are involved—to remove the refractory oxide of aluminium (alumina), and to ensure the making of a good, clean joint, free from inclusions. The following points for the application of welding rods have particular reference to the pure aluminium rod and the aluminium alloy rods described below.

See that your flux fulfils these requirements :

- (1) the ability to dissolve the aluminium oxide and melt at about 100° – 150° C. below the melting-point of the alloy being welded ;
- (2) a specific gravity less than the molten alloy, so that it may float on the surface of the metal ;
- (3) the correct degree of viscosity ; and

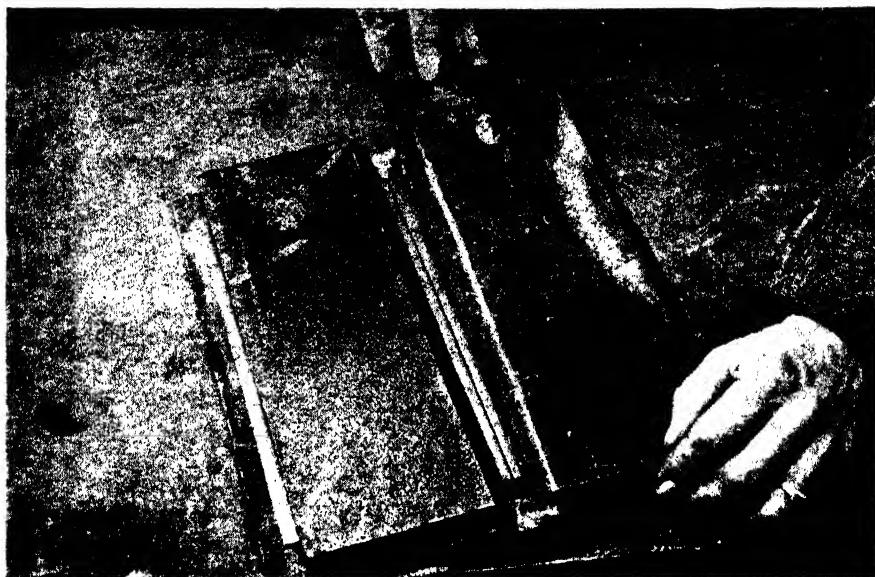


Fig. 5.— JIG FOR SHEET METAL BUTT WELD PARTLY ASSEMBLED
(*British Oxygen Co. Ltd.*)

- (4) the possession of the correct constituents to give it the foregoing properties, these constituents to be correctly proportioned and properly mixed.

The chief constituents of suitable fluxes are chlorides and fluorides of lithium, sodium and potassium. Of the various fluxes suitable for the welding of aluminium and aluminium alloys, Aluminium Flux, Air Ministry Flux and French Specification Flux are especially recommended. The choice of flux depends, of course, upon the nature of the material welded and upon the class of work. The flux may be applied either as a powder or paste ; but the welder is advised to use it sparingly in the interests of economy and efficiency.

Pure Aluminium Welding Rods

The "Alsa" pure aluminium welding rod contains about 99·5 per cent. pure aluminium, the remainder being small amounts of silicon, iron, etc. The mechanical properties of an all-weld-metal specimen deposited by the oxy-acetylene flame are as follows :

Yield stress	.	.	.	.	1·6 tons/sq. in.
Ultimate stress	.	.	.	.	4·1 tons/sq. in.
Elongation	.	.	.	.	38·0 per cent. in 2 in.
Brinell hardness	.	.	.	.	13·7.
Izod impact value	.	.	.	.	12·8 ft. lb.



*Fig. 6. - CLAMPING DOWN JIG FOR SHEET METAL BUTT WELD
(British Oxygen Co. Ltd.)*

This rod is widely used for the welding of sheet aluminium for petrol tanks, oil tanks, foodstuff containers, chemical plant and aluminium vessels of all kinds, and for the welding of aluminium articles which are subsequently submitted to "anodic" treatment.

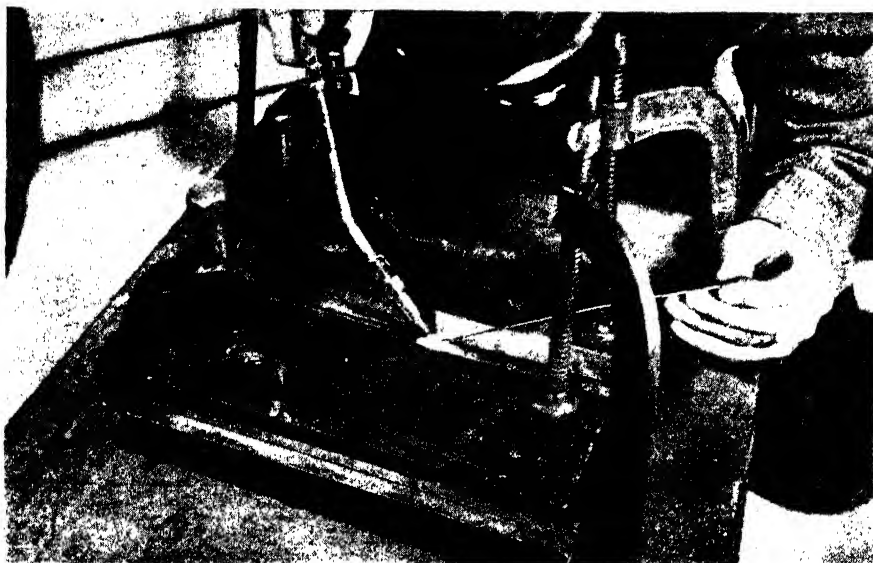
SHEET ALUMINIUM

Sheet aluminium is usually 99-99.5 per cent. pure aluminium, together with small amounts of silicon, iron, etc. It is widely used for vessels and containers.

Preparation for Welding

Sheet aluminium is usually clean, except for a very thin layer of oxide, which may be removed by wire-brushing the sheets in the neighbourhood of the weld. Preparation of the edges when welding sheet aluminium is similar to the preparation adopted for other non-ferrous metals.

In the case of sheet aluminium of 16 gauge or less, flange it to a depth equal to twice the thickness of the sheet. Butt welding without bevelling is recommended for sheet aluminium of 16-gauge to $\frac{1}{8}$ -in. thickness, whilst for greater thicknesses bevelling to an included angle of 90° should be adopted. A method used for large work is to employ two welders working simultaneously from opposite sides of the plate and welding in a vertical plane. This is known as the "two-operator vertical" method.



*Fig. 7.—SHEET METAL BUTT WELD IN PROGRESS IN JIG, SHOWING TYPES OF CRAMPS IN USE
(British Oxygen Co. Ltd.)*

The procedure known as notching has particular application when unbevelled edges are butted close together, and assists not only in the activity of the flux but in the penetration of the weld. Instructions may be summarised thus : Saw-cut the edges inward to a depth about equal to the thickness of the material, seeing that the cuts are about twice the thickness of the material apart. Notching also has a useful application when bevelled edge is joined on to unbevelled edge ; in this instance the notching is applied to the unbevelled edge ; again, notching ensures adequate penetration in the case of the bottom edges of bevels closely butted, or where the edges are not bevelled for their full thickness.

Tacking is sometimes necessary for the maintenance of edges in correct alignment. Where tacking is not employed, take care that the correct taper allowance ($1/5$ in. per foot) is made for heat-effect upon the metal.

For flanged edges in sheet aluminium of 16-gauge thickness and less, no welding rod need be used. For thickness up to $\frac{3}{8}$ in. ensure that the diameter of the rod is approximately equal to, or greater than, the thickness of the sheet. (In practice, rods greater than $\frac{1}{4}$ in. diameter are rarely used.)

Method of Welding

For single-operator underhand welding on sheet up to $3/16$ in. or $\frac{1}{4}$ in.,

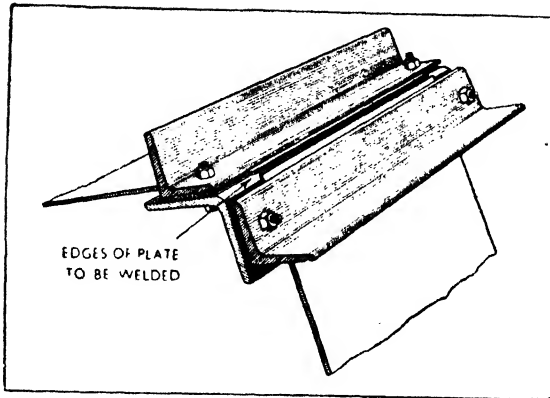


Fig. 8.—JIG FOR WELDING CORNERS IN SHEET METAL
(British Oxygen Co. Ltd.)

When welding aluminium remember that an acceleration of welding speed takes place during welding. This is due to the quick rise in temperature of the metal surrounding the edges as a result of the high thermal conductivity of the aluminium, and the phenomenon is apt to constitute something of a problem for beginners. The speed must be kept up with the acceleration and no attempt should be made to withdraw the flame partly, with the object of slowing down the speed. Once master the essentials, however, and excellent welds, quite invisible after dressing and polishing, can be made.

Finishing the Weld

When finishing the weld, remove every trace of flux, as the fluxes used for aluminium welding are strongly corrosive in action. Removal of the flux can be effected by washing in warm water and then brushing vigorously with a metal brush; wherever possible, dip the welded article in a

warm 5 per cent. solution of nitric acid and immediately rinse in warm water.

A second, precautionary washing, carried out after a few days, may sometimes be advisable.

Heat treatment and mechanical work on the metal brings about a marked improvement in the

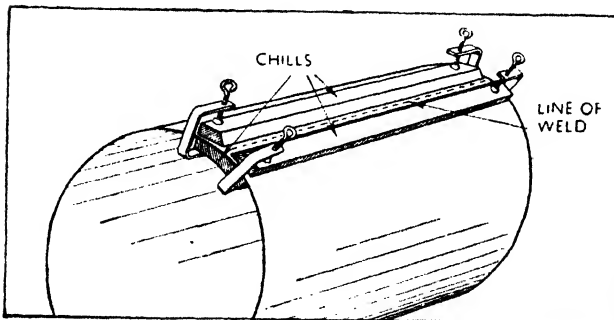


Fig. 9.—USE OF CHILLS ON THIN SHEET METAL SEAM
(British Oxygen Co. Ltd.)

properties of the weld. As deposited, the aluminium has a cast structure and is rather coarse grained, but on blow-pipe annealing and hammering, the metal is subject to considerable refinement of grain; further, the mechanical properties are rendered equal to, or better than, the unwelded sheet.

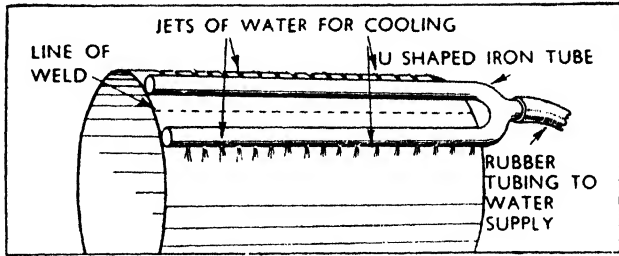


Fig. 10.—ANOTHER METHOD FOR PREVENTING DISTORTION WHEN WELDING SEAM ON TANK OR DRUM
(British Oxygen Co. Ltd.)

OXY-ACETYLENE WELDING OF COPPER

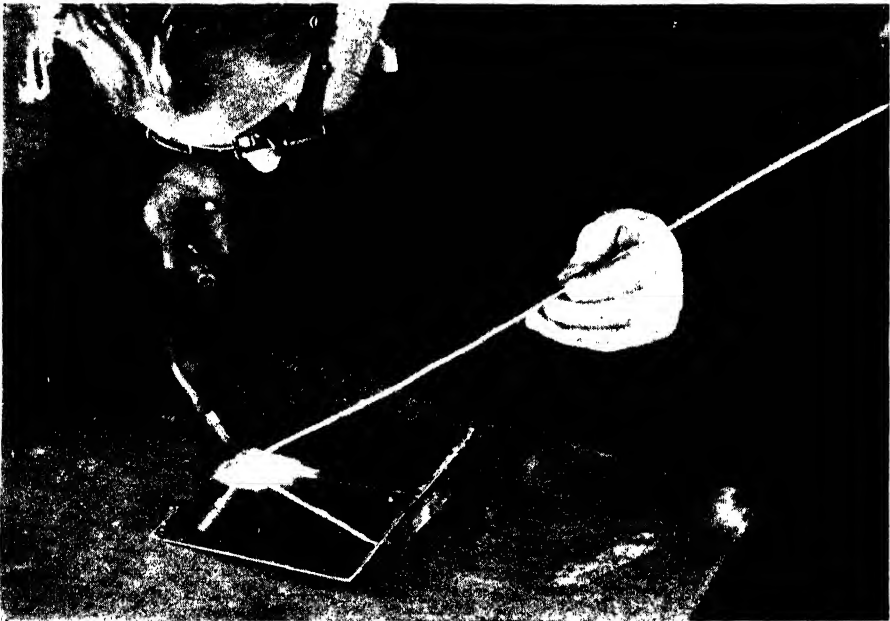
Besides hard-soldering, soft-soldering, brazing, bronze-welding, riveting and screwing, copper may also be welded. There were, however, many difficulties in the way of the development of copper welding to its present satisfactory stage. The ready absorption of oxygen from the atmosphere, whenever copper is heated above a few hundred degrees centigrade, has hitherto constituted one, although not the chief, of these difficulties.

This in itself, however, is not necessarily harmful. Copper has been used for perhaps five or ten thousand years, and it may be assumed that the necessity of preparing deoxidised copper before making the many implements (of which abundant traces have been found in later days) was not then considered. Much modern industrial copper does, in fact, contain a certain amount of oxygen, present in the metal as cuprous oxide.

Standard Copper and Deoxidised Copper

Of the three grades of ordinary tough pitch copper, each contains a small percentage of oxygen. High conductivity copper contains more than 99.9 per cent. of pure copper, and finds widespread use on account of its high thermal and electrical conductivity; best select copper, the impurity content of which is slightly higher than that of high conductivity, is sufficiently pure for the majority of applications, but its use is not advisable for electrical purposes; arsenical copper contains arsenic in amounts up to 5 per cent., the arsenic being added for the purpose of increasing the ease of working with the metal, raising the recrystallisation or annealing temperature, hardening the copper, and generally making it more useful for most purposes.

In order to overcome the welding difficulties inherent in each of these grades—and for reasons already detailed—a grade of copper known as “deoxidised” copper has been introduced. Deoxidisation is effected



(British Oxygen Co., Ltd.)

Fig. 11.—WELDING SHEET ALUMINIUM

Showing angle of rod and blowpipe at commencement of weld, blowpipe being held at about 40° – 50° and welding rod 30° – 40° .

by adding to the melt, in the final stages of manufacture, a small quantity of some deoxidising element such as phosphorus. The union of the phosphorus with the oxygen in the copper forms a volatile oxide of phosphorus which, when evaporated, leaves the metal free from oxygen. At the same time a small amount of phosphorus is left in the metal to act as a deoxidiser in welding operations, and this small difference has rendered possible the production of readily weldable grades of copper. The advantages gained from welding in general may now be obtained with copper joints.

Fluxes

It will generally be found necessary to use a flux when welding long lengths of the same copper for constructional purposes.

In order to get the best results, borax—the chief constituent of copper fluxes—should be compounded with some other chemicals. If ordinary borax is used alone, the object of the flux—which is the dissolving of any surface oxide and the forming of a protective layer over the molten metal—will not be attained; a very hard scale of copper borate will be formed. The use of a flux containing compounds which increase the solvent power of the flux will not only ensure better results but will, at



Fig. 12.—WELDING SHEET ALUMINIUM

(British Oxygen Co., Ltd.)

Showing angle of rod and blowpipe towards end of weld.

the same time, prevent the formation of a hard borax compound on cooling. Fluxes suitable for copper-welding purposes are of the copper-silver (for copper-silver rods) and brass and copper (for "poro" rods) varieties.

Blowpipe Nozzle Sizes

Silver excepted, copper conducts heat far more rapidly than any of the common metals.

A larger size nozzle must therefore be fitted to the blowpipe than would be used for an equivalent thickness of steel. Manufacturers of blowpipes usually supply a table showing the size of nozzle recommended for various thicknesses of plate, single-operator underhand welding.

The Flame Required

Instruction for flame and blowpipe adjustment may be summarised in the words, "Work with an absolutely neutral flame." An excess of oxygen in the flame tends towards the formation of copper oxide, unavoidably resulting in a brittle weld; an excess of acetylene, on the other hand, only increases the danger of a defective weld, for copper, in the molten and plastic stage, readily dissolves gases. A preponderance of acetylene in the flame produces, then, the tendency for the molten metal to dissolve gases; the molten metal will dissolve hydrogen, which will, in turn, react with any oxygen present in the copper to form water

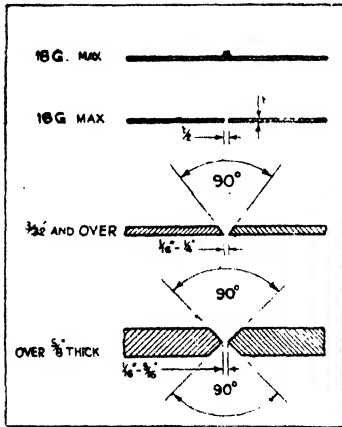


Fig. 13.—EDGE PREPARATION FOR COPPER—UNDERHAND WELDING
(British Oxygen Co. Ltd.)

vapour; the vapour will escape from the molten metal in the form of bubbles, and so produce a porous weld—or, alternatively, the gases will be trapped in the metal and give rise to a brittle and faulty structure.

To secure the requisite flame neutralisation, first obtain a flame having an excess of acetylene, then gradually reduce the acetylene supply until there is the merest haze of acetylene round the centre cone of the blowpipe flame

Preparation for Welding Sheet Copper

Before starting to weld, see that the metal is vigorously cleaned.

An illustration (Fig. 13) shows the type of edge preparation advisable for sheet

copper.

A flash or flange, the height of which should be about twice the thickness of the welded metal, is recommended in the case of thin sheet copper having a maximum thickness of 18 gauge. See that the flange has a square corner, otherwise it will be impossible to obtain a flat sheet after welding. The abutting edges may be in contact, and the metal run down with the blowpipe without the need of a welding rod.

For thicknesses of sheet copper up to 16 gauge—using a plain butt weld without any bevelling—the plates should be separated before welding by a gap equal to about half the thickness of the sheet.

For plate up to $\frac{5}{8}$ in. thickness, a single bevel, having an included angle of 90° , is necessary. Penetration should not be sacrificed for the sake of a small weld. For material above $\frac{5}{8}$ in., bevel from both sides of the plates.

Fusion Welding of Copper Tubes

In cases of sanitary and water services piping, it is usual to bronze-weld copper pipes wherever practicable. Although this type of work does not come within the scope of the sheet-metal worker, the joining of thin tubes, such as are used for ducting, has often to be considered.

The method of preparing joints in copper tubes is given in the illustration (Fig. 14). For butt welds in thin tubes, upset the edges of the pipe and run down the copper by the blowpipe. For butt welds in thicker tubes, butt the tubes together, leaving a small gap equal to about the thickness of the tube; the joints may then be welded in the usual manner.

There are two methods of making a T joint. In the first, a hole is cut in the tube, and the material is then worked out in the usual copper-

smith's manner. A butt joint is then made. The second method of making a T branch is to cut a hole in the pipe and to shape the abutting tube to fit on to the hole. A fillet joint is made at the junction.

Welding Methods

For normal thicknesses of plate, use the leftward modification of the underhand technique. Hold the blowpipe fairly steeply in relation to the plate (Fig. 15), so directing as much of the heat as possible to the actual point of welding. Give the blowpipe a slight side to side motion, confining this motion to the weld seam. Do not remove the rod from the flame, but keep it in the molten pool; and see that the blowpipe is kept at a small distance, say $\frac{3}{8}$ in., away from the surface of the metal. When using flux, apply it (preferably in the form of paste) previously to both sides of the plate. If necessary, also paint the welding rod with the paste before welding commences.

When vertical-position welding is possible, the two-operator method should preferably be adopted.

A backing strip, such as is commonly used to support the seam in copper welding, consists of a length of steel angle-iron or of any material of suitable shape and dimensions. The interposition of a sheet of asbestos between the copper and the backing strip is also a help in the localisation of the heat applied to the copper sheet. Failure to dry out the asbestos before use may lead to the trapping of latent water vapour (from the asbestos) in the metal, in which case a weld of poor mechanical properties will result.

When welding long seams in copper plate it is essential to maintain the correct distance between the edges. The most suitable and successful method of doing this is taper-spacing by means of clamps. (Remember that copper is a soft metal; wedges should not be used in such a manner that they

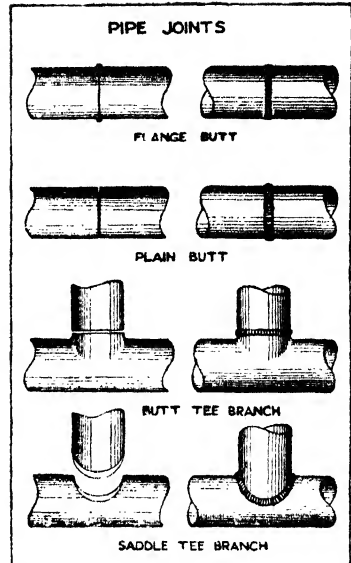


Fig. 14.—COPPER WELDED PIPE JOINTS

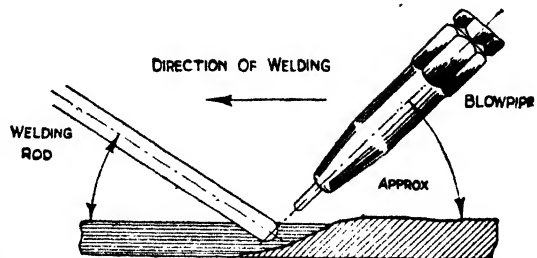


Fig. 15.—COPPER WELDING — UNDERHAND TECHNIQUE

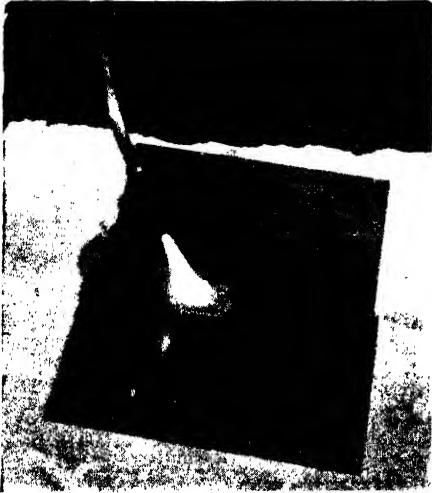


Fig. 16.--HEATING A PIECE OF COPPER
 $\frac{1}{16}$ -IN. SHEET BEFORE WELDING

Bring edges and surrounding sheet to dull red heat. (*British Oxygen Co. Ltd.*)

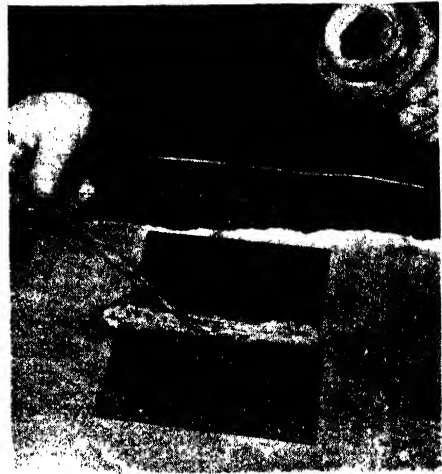


Fig. 17. - BRUSHING ON A PASTE FLUX

The next step. This should be done on both sides of the sheets. (*British Oxygen Co. Ltd.*)

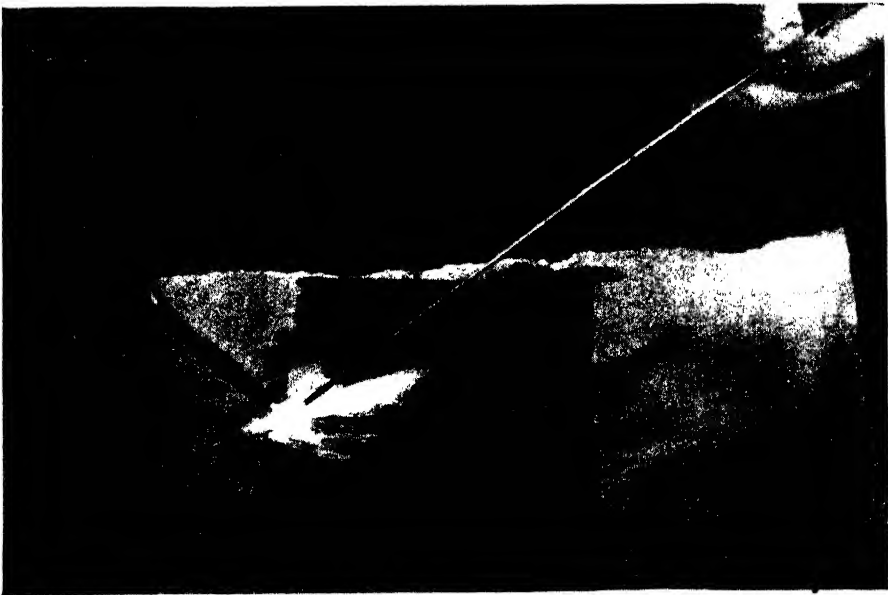


Fig. 18.—COMMENCING TO WELD COPPER SHEET, SHOWING ANGLE OF ROD AND BLOWPIPE

Note backing sheet of asbestos, which should be well dry and slightly sloped up towards finishing end of weld. (*British Oxygen Co. Ltd.*)

become forced into the heated metal.)

When welding longitudinal seams on copper tanks use the leftward, or vertical, method of welding, taking care not to commence welding at the beginning of the seam, but rather commencing at a distance of about one-third of the total length from the end. Then weld throughout two-thirds of the length of the seam in the direction *A-B* (Fig. 25). Beginning again at the previous starting point, finish the remainder of the weld in the direction *A-C*.

After-treatment of Welds

The only after-welding treatment which is generally practised and approved is the *light hammering* of the weld, whilst the copper is still at a dull red heat. Many advantages accrue from a light and careful hammering—excessive grain growth is prevented, the copper cuprous oxide eutectic is broken up, and the surface of the weld is strengthened and hardened. Hammering is best applied to the weld and to the metal adjacent to the weld. It should be light and great care should be taken not to damage the surface. Copper should be hammered all the time it shows a red heat, but never whilst it is “black” hot, otherwise it will become hard and brittle.

This treatment is also recommended when the copper is of the non-deoxidised variety.

Wherever feasible, it is advisable to anneal after hammering by bringing the weld again to a dull red heat and quenching in water. Annealing effects an increase in uniformity of the metal in and around the weld.

If it is not possible to hammer the weld at red heat, it may be hammered cold.

Cold metal hammering, wherever its employment is warranted, strengthens the mechanical properties of the metal and consolidates the surface.

If it is desired to hammer a weld flat with the surface of the sheet heat the copper to a dull red heat and thoroughly hammer with a plan-

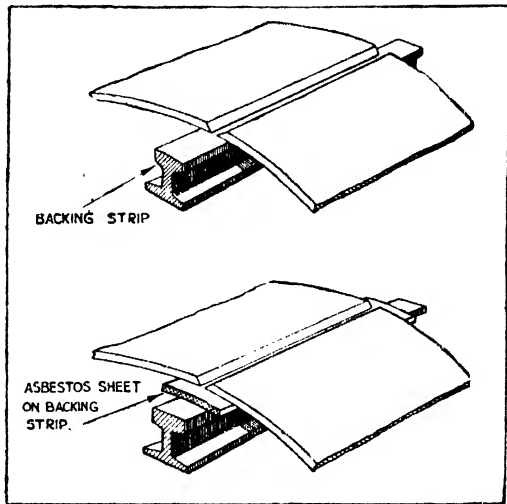


Fig. 19.—METHOD OF SUPPORTING A COPPER WELD

A piece of asbestos sheet placed under the seam will help to maintain the heat in the seam.

(British Oxygen Co. Ltd.)



Fig. 20.—ANGLE OF ROD AND BLOWPIPE
TOWARDS END OF WELD

All welds should be completed in one run. (*British Oxygen Co. Ltd.*)

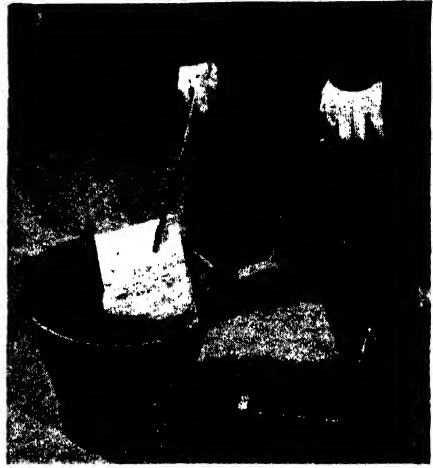


Fig. 21.—ANNEALING BEFORE HAMMERING
WELD

Raise to dull red heat, if necessary, and quench in water.

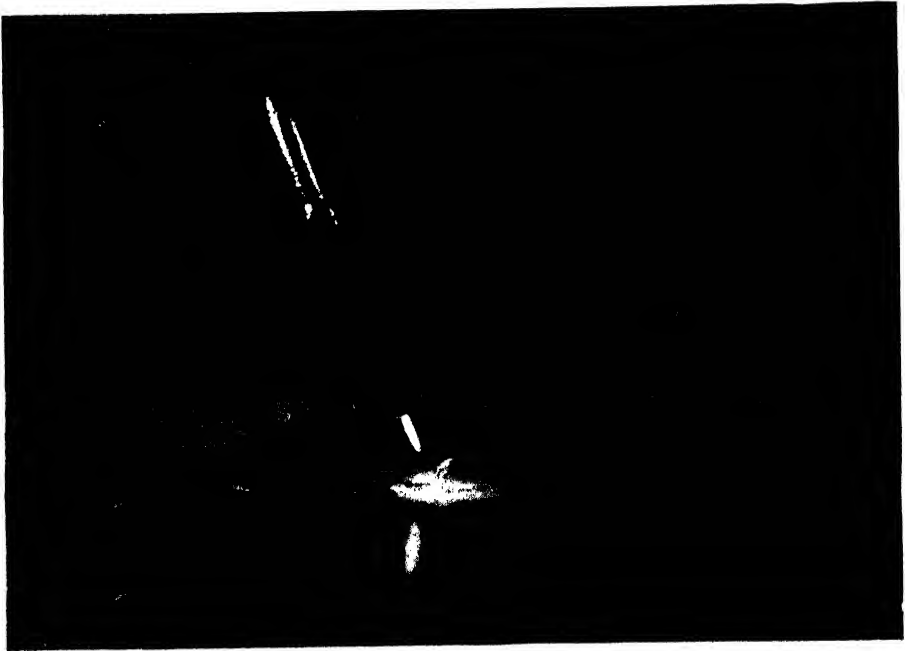


Fig. 22.—SHOWING DISTANCE OF FLAME FROM WORK

Never touch work with white cone of flame, but keep it about $\frac{1}{8}$ in. to $\frac{3}{8}$ in. away. (*British Oxygen Co. Ltd.*)



Fig. 23.—COPPER WELD PARTLY DRESSED WITH PLANISHING HAMMER
When working copper cold, frequent annealing is required. (*British Oxygen Co. Ltd.*)

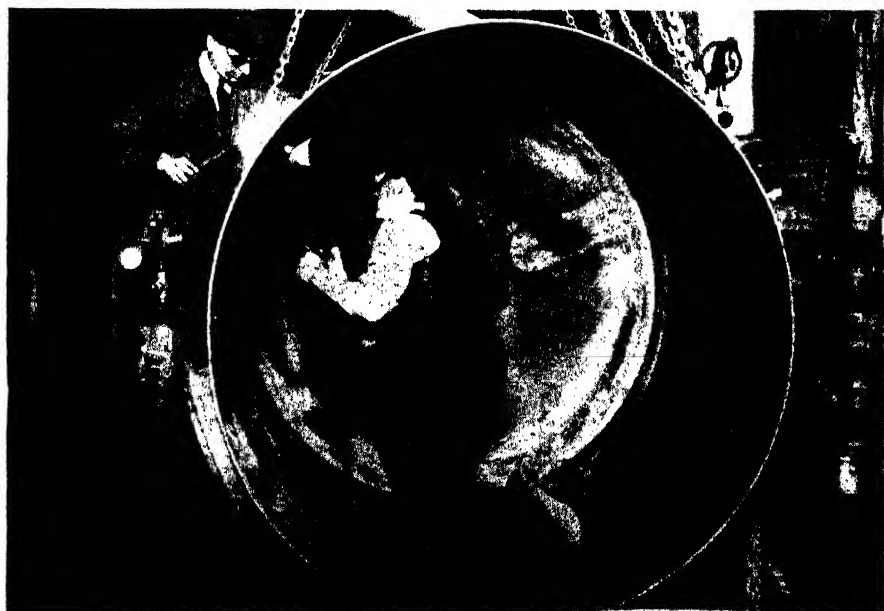


Fig. 24.—WELDING A LARGE COPPER VESSEL BY THE TWO-OPERATOR METHOD

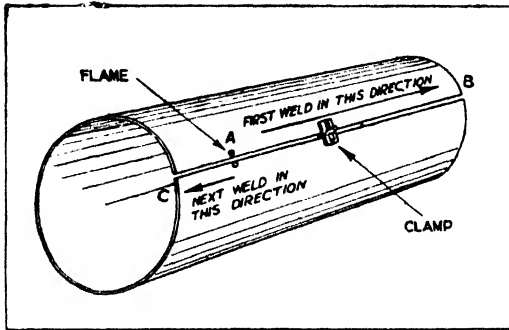


Fig. 25.—WELDING A LONG SEAM IN COPPER
(British Oxygen Co. Ltd.)

ishing hammer until flat, reheating if necessary. After hammering is finished, bring again to a dull red heat and quench in water.

When dealing with copper fusion welded pipe joints, hammering is rather more difficult to do. By heating the pipe joint, after completion of welding, and then plunging into water, or if on the site, quenching in water, the joint is made more effi-

cient than when it is left untouched.

When welds have to be worked cold (see Figs. 21 and 23), the work should be frequently annealed or softened by making red hot and quenching in cold water. Always anneal the copper as soon as it ceases to yield freely to the blows of the hammer.

Strength of Welds

The best testimony to the properties of a successful copper weld is the fact that it is possible to hammer out a butt weld to a very small fraction of its original thickness without the appearance or development of incipient cracking. Moreover, the excellent ductility of copper welds allows a bending through 180° without any signs of cracking.

Welded copper joints, when carried out in accordance with the best technique, present advantages of homogeneity, smoothness, uniformity, equal expansion and contraction, and good appearance; and it can reasonably be said that welded copper joints may with advantage replace other types of joints.

Welding Rods

The properties of three rods for copper welding—"Alda" copper, "Premag" deoxidised copper and "Poro" copper—are summarised below.

Properties of All-weld-metal Deposited "Alda" Copper Silver Rod

Yield stress	3.91 tons/sq. in.
Ultimate stress	12.25 tons/sq. in.
Elongation in 2 in.	40.0 per cent.
Izod impact value	40 ft. lb.
Brinell hardness	63.5

Mechanical Properties of All-weld-metal Deposited "Premag"

Yield stress	3.60 tons/sq. in.
Ultimate stress	13.72 tons/sq. in.
Elongation in 2 in.	46.0 per cent.
Izod impact value	43 ft. lb.
Brinell hardness	52.3

Mechanical Properties of All-weld-metal Deposited "Poro"

Yield stress	5.48 tons/sq. in.
Ultimate stress	15.68 tons/sq. in.
Elongation in 2 in.	48.0 per cent.
Izod impact value	37.5 ft. lb.
Brinell hardness	53

The "Poro" copper welding rod gives a deposit having high mechanical strength, and should be used when exceptional stress is to be applied to the joint. We are indebted to the British Oxygen Co., Ltd., for supplying information upon which this section is based.

ARC WELDING OF THIN PLATE

Although lighter sections can be welded better with the oxy-acetylene process than with the electric arc method, on account of the great flexibility of the former in regard to heat control, the oxy-acetylene process suffers from certain disadvantages which may in some cases render it unsuitable for the fabrication of those structures which depend for their strength on carefully designed arrangement of rigid components, pressed or otherwise, shaped from light-gauge steel.

The diffused nature of the applied heat results in the partial relief of the cold working stress put into the work by the rolling of the sheet or subsequent operations. Such stress relieving is not uniform throughout the structure but confined to the area of welding, with the natural result that buckling and other forms of distortion take place which are expensive and sometimes impossible to rectify. The intensely localised nature of the electric arc results in less disturbance of the plate with proportionately less distortion, which fact is responsible for the preference given to this method over the oxy-acetylene process.

Lowest Limit of Plate Thickness

For practical purposes the lowest limit in thickness that can be welded in the present state of arc welding development is No. 20 S.W.G.

(.036 in.). Such seams as butts and outside corners on this thickness sheet are now being welded in commercial practice satisfactorily.

These remarks, however, cannot be applied to "inside corner" welds, which, until quite recently, have been found impossible to make by conventional methods. The difficulties met with are due to the contour of the corner, associated with the low permissible heat input; the former restricts the free flowing of the slag away from the depositing metal and the latter is insufficient for their effective separation; fusion is obstructed and the resulting weld generally is unsatisfactory. It might be thought, from what has been said above, that a bare wire or lightly coated electrode would provide the solution. This, however, is not the case, since the arc instability associated with these types, coupled with lack of rigidity and tendency of the electrode tip to stick to the plate, renders the operation impracticable.

Suitable Electrode

The quest for an electrode suitable for this class of work has been the subject of research for some time past, and the problem has now been solved by the production of an electrode embodying the characteristics for coping with the above-mentioned special difficulties.

Welding Hints

Successful welding of light-gauge steel demands the observance of three important conditions: close fitting of abutting edges, the right type and gauge of electrode and accurate current adjustment. Either D.C. or A.C. is suitable, providing the supply is steady and capable of adjustment in 1 amp. steps. The open voltage should not be less than 60 in the case of D.C. and 80 in the case of A.C. Within reasonable limits the higher the open circuit voltage the better, as thereby more energy is available for setting up the arc with the lower current adjustments employed.

Unless care is taken to see that the edges or surfaces to be joined are in close contact along the seam, the heat conductivity of the weld area will be interrupted and excess local heat will cause burning through wherever a gap occurs. Joint contact is maintained by tack welds 3 to 6 in. apart (varying with the thickness from 20 S.W.G. to $\frac{1}{8}$ in.).

The welding operation, which takes a little time and practice to acquire, consists of striking the arc and passing the electrode tip, with the shortest possible arc, rapidly along the seam at a uniform rate of deposition per unit length without any sideways movement.

The following table shows the gauge of electrode and current values recommended for various thicknesses:—

GAUGE OF ELECTRODE AND CURRENT VALUES

Thickness of material (S.W.G.)	Gauge of electrode (S.W.G.)	Current in amps.		
		Outside corner	Butt	Inside corner
12	12	50	60	60
14	14	37	42	42
16	14	34	38	40
18	16	30	35	35
20	16	20	15	25

RESISTANCE WELDING OF ALUMINIUM AND ALUMINIUM ALLOYS

Before attempting to give details of modern methods of welding aluminium, it is as well that the problems should be thoroughly understood. One of the most important is the high electrical conductivity of the metal. Due to this property, it is essential that a very high current should flow in order to raise the metal to a welding temperature, and in this respect the good thermal conductivity of aluminium is also an adverse factor, for the heat generated by the flow of current is very quickly spread and dissipated in the material surrounding the path of the current. It is small wonder that when the welding of aluminium was attempted on machines normally used for steel, the results were quite unreliable and useless, due to the current available being insufficient to produce the requisite heat.

Yet another factor to be overcome was the failure on the part of welders to realise that as soon as aluminium comes into contact with air, an oxide film forms on the surface of the metal and that this film, besides having a very high melting-point, is an insulator and therefore must be removed before current will flow and welding commence. It was, perhaps, natural that due to the bright and clean appearance of aluminium, welders should have imagined they had an ideal surface for welding. Neglect to remove the oxide film, either by chemical or mechanical means, invariably resulted in failure to make satisfactory welds.

Spot Welding

It is probably due to the rapidly increasing production of metal aircraft that the importance of being able to spot weld aluminium and

aluminium alloys has arisen, though there are, of course, many other applications where its usefulness is realised.

The number of rivets on a modern aeroplane may run into scores of thousands and, besides the high cost of drilling or punching of holes and inserting and heading of these rivets, there are disadvantages of extra weight and interference to airflow by protruding rivet heads. By means of spot welding, these disadvantages could be avoided, and much research has been carried out in recent years to obtain satisfactory machines for welding aluminium alloys, especially those used in aircraft production.

Special Machines for Aluminium Alloys

Very much larger capacity machines than those normally used for steel have been made, and there are now on the market spot welding machines of 500 kVA capacity, specially designed for aluminium alloy welding. These machines are capable of welding up to two thicknesses of $\frac{1}{8}$ in. with ease, and the variables of welding are under easy and accurate control. They operate from an alternating current supply and are either thyatron or ignitron controlled so as to permit weld currents being applied for variable periods down to one cycle of the supply current. Mechanical pressure is also most important, and it is now usual to operate the top electrode pneumatically in such a manner that when once the correct pressure has been decided upon, that pressure can be maintained for an indefinite number of welds and can be reset as and when required. Due to the high power of these machines very short welding periods only are necessary, thus little heat is wasted in warming up material outside the welding zone and the temper of the metal except at short distances from the weld is not altered. This latter point is of great importance as the majority of the aircraft materials are heat-treated or strain-hardened alloys of the "Alclad" or N.A.57S types respectively, and any appreciable reheating would reduce their mechanical properties and resistance to corrosion.

Special Direct Current Machines

There is another type of spot welding machine which is operated from a direct current supply. This machine has been developed to produce welds between materials of thicknesses up to those handled by the alternating current machines, but one of the points in its favour is that it takes the load from the supply over a period, thus avoiding high instantaneous loads on the mains. It is also adapted to give a special pressure cycle which operates as follows: Full pneumatic pressure (giving a stress approaching the crushing strength of the materials)

applied between the electrodes and the material. The pressure is then reduced while the current flows ; this having the effect of increasing the electrical resistance over the area of contact. When the current ceases to flow the full mechanical pressure is restored, thus tending to forge the weld and break down its natural cast structure.

Both alternating and direct current machines are capable of making satisfactory welds and are being used in rapidly increasing numbers by the aircraft industry.

Preparation of Material

Attention has already been drawn to the importance which surface conditions play on the results of the welding operation. In the case of pure aluminium and many of the alloys a scratch-brushed surface is usually satisfactory, but a chemical etch is to be preferred, and for "Alclad" material this latter method of preparation is strongly to be recommended. "Alclad" material, which is extensively used in aircraft construction, consists of a strong alloy core between two comparatively thin coatings of pure aluminium, and unless scratch-brushing is carried out very carefully on this material, it may result in the removal of a large percentage of the pure aluminium coating.

A Satisfactory Etching Solution

An etching solution which has been found most satisfactory consists of 2.9 lb. of gum tragacanth in 8 gallons of boiling water, to which is added 10 lb. of 30 per cent. hydrofluoric acid. If difficulty is experienced with the dissolving of gum tragacanth, its solution may be accelerated by adding 7 lb. of denatured alcohol, but this is not an essential constituent. The material to be welded is either dipped in the etching solution or painted with it, and after being in contact for from fifteen to thirty seconds it must be washed down with water. The cleaned surface may be preserved for several days by means of the application of a thin film of light oil.

Operating Notes

It is essential that when once a machine has been set-up to weld satisfactorily, the shape of the electrode tips should be maintained, and any tendency to mushroom or to increase the area of contact must be prevented by giving constant attention to the tips and changing them when necessary.

Use of Special Alloy Electrode Tips

Numerous special alloy tips of high conductivity and hard-wearing

properties are now on the market, and it is advisable to take the advice of firms specialising in their production. Use of the correct material will greatly assist in the welding operation, and, though the first costs are rather high, the alloy tips stand up to the work much more satisfactorily than hard-drawn copper, and prove a thoroughly economical proposition.

Water Cooling

Tips should be water cooled as near to the contact points as possible, and it is essential that they are kept scrupulously clean, otherwise overheating will occur between them and the work, resulting in pitted welds and a poor surface finish on the work, which is liable to increase corrosion risks and reduce the strength of the welds. It is mainly due to variations of contact resistance between tips and work, and the two contacting faces of the work, that the strength of the welds varies. In a modern spot welding machine the other variables are under strict control, thus it will be seen that only by taking special care as regards etching the surfaces of the work and maintaining clean electrode tips is it possible even to hope for welds of uniform properties.

" Setting Up " a Machine

The actual " set up " of a machine is best made experimentally for any particular article, but the following table gives a fairly accurate basis on which to prepare the settings of time, welding current and mechanical pressure for various thicknesses of aluminium alloy sheet.

Little variation of time or current is necessary for the welding of different alloys, but, generally speaking, greater mechanical pressures are to be recommended for welding the harder high-strength alloys.

SPOT WELDING ALUMINIUM ALLOY SHEET

<i>Thickness of material</i>	<i>Cycles *</i>	<i>Time (Seconds)</i>	<i>Welding current (Amperes)</i>	<i>Electrode pressure during welding (Pounds)</i>
·022	1	1/50	17,000	300- 500
·036	2	1/25	21,000	400- 650
·048	3	3/50	23,000	450- 700
·064	4	2/25	26,000	500- 800
·080	5	1/10	29,000	600- 900
·128	8	4/25	36,000	700-1,200

* Based on 50 cycles per second.

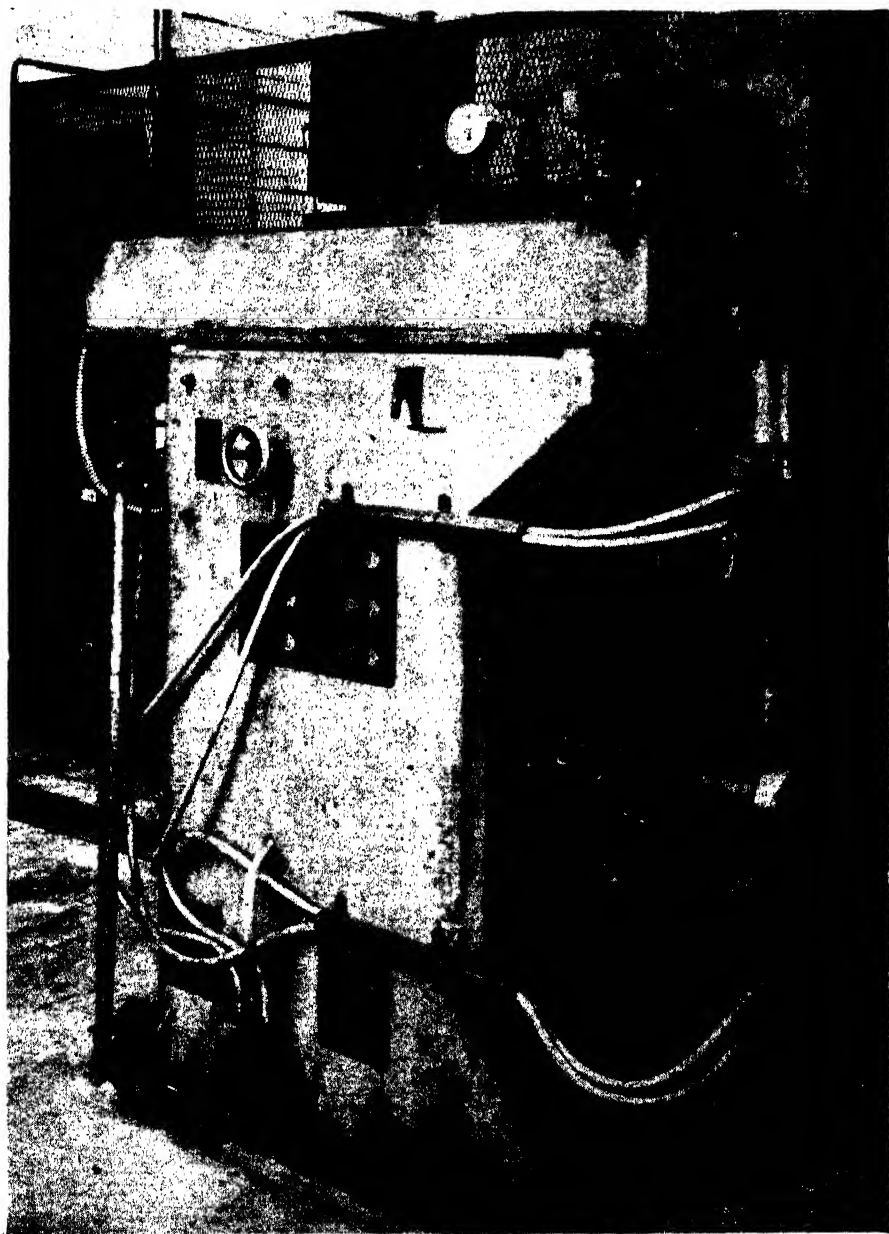


Fig. 26.—A SPOT WELDER OF 350 kVA CAPACITY, HAVING THYRATON CONTROL, PRIMARILY DESIGNED FOR THE WELDING OF ALUMINIUM AND ITS ALLOYS (*Metropolitan Vickers Electrical Co., Ltd.*)

Design for Spot Welding

As in the case of spot welded steel work, the design of the article or structure should be such that the welds are not subject to severe tensile stresses. While this condition is true of riveted work, it is of even more importance where spot welding is concerned. The shear strength is often equal to or even greater than that of a similar riveted article, and it thus becomes essential that when designing for spot welded work all welds are so arranged that they are in shear and not in tension. Tests on spot welded joints are usually made on sections of the joint consisting of one or more spot welds and the efficiency quoted is the ratio of the strength of 1 in. of width of the joint to that of 1 in. of width of continuous metal.

A general idea of the type of strength which may be expected is given by the following table :—

STRENGTH OF SPOT WELDED JOINTS

<i>Material</i>	<i>Thickness (Inches)</i>	<i>Number of spots</i>	<i>Average strength (Pounds)</i>	<i>Efficiency (Per cent.)</i>
NA.280	.050	2	420	68
NA.51SW	.050	2	775	46
NA.17ST	.050	2	880	29
"Alclad"				
NA.17ST	.050	2	910	32

Seam Welding

Seam welding of aluminium and aluminium alloys, though not in such general use as spot welding, is in reality a method whereby successive spot welds overlap one another to form a continuous seam. Special alloy rolls are used in place of spot welding electrodes, and rather more current is employed than in the spot welding process. This is partly due to the short-circuiting effect of the section of seam already welded, but the resulting loss is not very great. The overlapping spots are produced by the application of very short "on" periods of power followed by longer "off" periods. During the whole process the rolls are revolving and moving the point of contact between the parts being welded, thus, by correlating the correct "on" and "off" periods with the speed at which the rolls revolve, a seam can be formed with spots either overlapping or slightly spaced according to which type of seam is desired. The periods "on" and "off" vary according to the type of joint, to the alloy and to the thicknesses being welded, but, in general, for continuous seams the "on" period is about 20-40 per cent. of the "off" period.

Cleaning Surfaces of Sheets

The conditions as regards cleanliness of the surface of the alloys being welded and of the roller electrodes are of even greater importance in the case of seam welding than in spot welding, and it is strongly advised that a suitable chemical etch should be employed for the sheets and that great care be taken to ensure that the original shape of the rollers is maintained. On some types of

machines this latter condition is obtained by mechanical means incorporated in the welding head, but where this is not so, a constant check should be maintained.

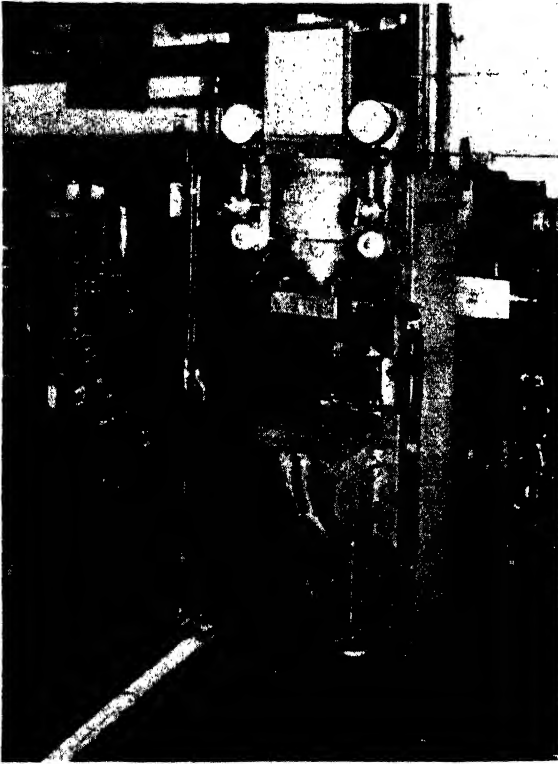


Fig. 27.—120-kVA SPOT WELDER WITH IGNITRON CONTROL (B.T.H.)

Butt Welding

The high electrical and thermal conductivities of aluminium and aluminium alloys have also to be taken into account when butt welding these materials, but provided sufficient power is available and the sections being welded are not too complicated, satisfactory results are obtainable by pure resistance welding practice; that is to say,

without a preliminary “flashing” process. The parts are clamped in suitable electrodes, a predetermined mechanical pressure applied and followed by application of the electrical power. A limit switch is used to cut off the power when the necessary “upset” has been reached. Current distribution in the parts can, to a certain degree, be obtained by suitable electrode design, but as already stated, in the case of the more complicated types of sections, this becomes increasingly difficult to accomplish.

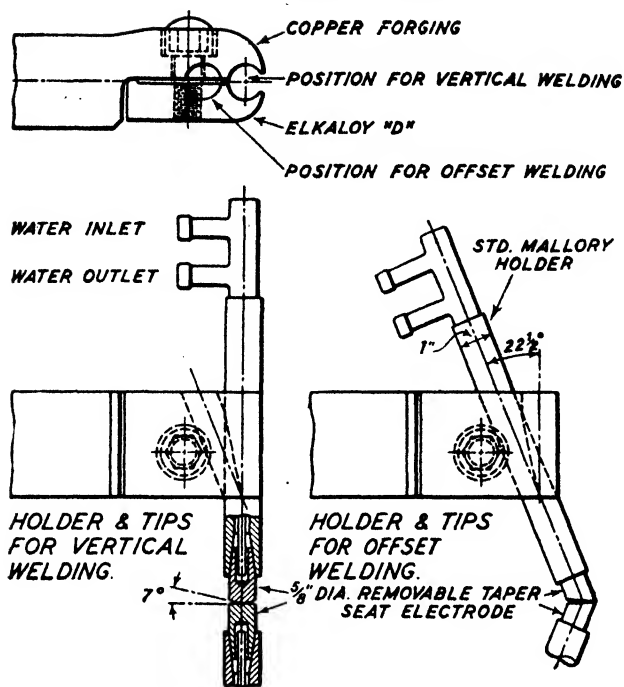


Fig. 28.—VERTICAL AND OFFSET HOLDERS AND REPLACEABLE TIPS FOR SPOT WELDING OF ALUMINIUM AND ITS ALLOYS (Mallory Metallurgical Products Ltd.)

Limits of Process

Spot and seam welding are carried out on strain-hardened and heat-treated aluminium alloys with comparatively little reduction in the strength of the remainder of the parts, but if these same alloys are butt welded, the heat generated throughout the entire butt welded section will tend to anneal that section and so reduce its strength. This condition somewhat limits the use of butt welding in the higher strength alloys, but there are still many fields of application where it can be used most

advantageously and in some cases reheat-treatment after welding will bring the tensile strength to about 70–80 per cent. of that of the unwelded material.

RESISTANCE WELDING OF COPPER AND ITS ALLOYS

The conditions for success in resistance welding copper and its alloys are much more critical than for mild steel, because of the inherent qualities of the copper, which has:—

- (1) Low electrical resistance.
- (2) High heat conductivity.
- (3) Comparatively low melting point.
- (4) Practically no plastic range.

Heat and pressure are necessary to make a weld, and the heat generated in the weld depends on $\text{Current}^2 \times \text{Resistance}$.

Obviously, without resistance there is no heating and therefore no weld.

The following table gives the comparative values :—

	<i>Specific Resistance</i>	<i>Electrical Conductivity</i>	<i>Heat Conductivity</i>	<i>Melting Temperature</i>
Copper	1.72	100 per cent.	.918	1,084° C.
Brass	6.99	20 per cent.	.285	930° C.
Mild Steel	11.85	15 per cent.	.140	1,500° C.

SPOT WELDING

When a spot in a sheet is being heated by the current, this heat is being conducted away into the mass of the sheet and into the cold electrodes. The heat input must be many times greater than the heat conducted away, so for high conductivity metals a high current density is required.

This makes possible a short welding time, and therefore reduces the heat losses. The heat may be more closely localised by the use of high resistance electrodes. These are usually tungsten copper, and the tungsten content may vary from 50 per cent. to over 90 per cent.

Such electrodes increase the local heating and keep their shape better than the copper as they are harder, and, as the hardness is due to the presence of the tungsten, they do not soften appreciably under heat.

With mild steel it is usual to work with a current density of 100,000 to 200,000 amps. per square inch of weld area.

With brass the current density may be ten times the above values, and with copper the values are higher still.

Spot Welding Copper Sheet

Mallory, of U.S.A., advise that 250 kVA be available for spot welding copper sheets of .04 in. in thickness, but such high values are seldom used in this country.

With thin sheets welds may be made with much lower current values by the use of pure tungsten or of tungsten-copper electrode tips with a high percentage of tungsten.

Welding Copper Wire to Steel

Copper connections are frequently welded. An example which might be quoted is the welding of copper wires of about 30 S.W.G. to the steel spindle of a small dynamo. Here a pure tungsten electrode is used in contact with the copper and an ordinary copper alloy in contact with the steel. About 4 kW is used, with a welding time of half a cycle or one-hundredth of a second.

The time is controlled by an electronic valve timer.

Welding Copper Wire to Brass

Another example is the welding of the copper wire interconnections in certain high-tension radio batteries. These are spot welded to the

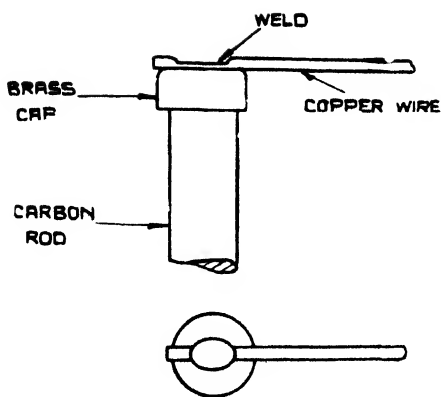


Fig. 29.—COPPER WIRE WELDED TO BRASS CAP IN HIGH-TENSION RADIO BATTERY

brass caps on the carbon rods. If such welds are examined it will be noticed that the wire is flattened considerably at the weld (Fig. 29).

Such a weld gives good electrical contact, but will not stand vibration or movement of the wire as this is naturally weak where the flattened section merges into the round.

The dynamo connections referred to are sealed from movement by celluloid varnish, while the high-tension battery connections are embedded in the bitumen used for sealing.

Accurate timing control is very necessary for success in welding copper and its alloys.

The ideal timing control for this work is certainly valve control, giving exact time in cycles and eliminating contactor errors, which are quite serious in welding times of five cycles or less.

Brass Welding

Brass is much easier to weld than copper, but is still very critical, as the micro-photographs of brass welds (Fig. 30) show. The welds are very different in size, but they were made under identical conditions, the only difference being that weld (b) had about three cycles longer welding time than (a). Electrode shape and contact area are important. For sheets up to $\frac{1}{16}$ in. in thickness a domed tip from $\frac{3}{16}$ in. to $\frac{3}{8}$ in. radius, well water-cooled, will usually give good results. The domed tip gives point contact at the start of the weld and therefore high current density.

Pressure on Electrodes

The mechanical pressure on the electrodes should be much lower for brass than for steel. With mild steel it is usual to work at about 15,000 ob. per square inch of weld area. Thus for steel:—

$\frac{1}{16}$ in. dia. spot = .003 sq. in. Pressure = 45 lb.

$\frac{1}{8}$ in. dia. spot = .0122 sq. in. Pressure = 185 lb.

$\frac{3}{16}$ in. dia. spot = .0276 sq. in. Pressure = 414 lb.

For brass the pressures may range from 12 to 100 lb., according to the size of the spot and the welding conditions, or approximately one-fourth of the pressures used for mild steel.

Maintenance of Electrodes

Unfortunately under heat and pressure the electrode tips spread and thus reduce the current density. If the diameter of contact is

doubled, the current density is divided by four. For this reason the electrode tips in welding brass require frequent attention and should be trimmed regularly. On certain jobs the electrodes may need trimming every hour, on others they may go without any attention but an occasional cleaning with emery cloth for several days. The tips become coated with volatilised zinc from the brass, hence the need to keep them clean.

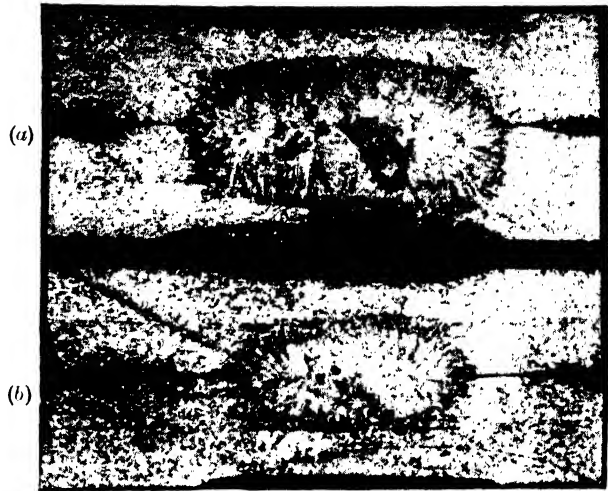


Fig. 30. MICRO-PHOTOGRAPHS OF BRASS SPOT WELDS

Welds made under identical conditions, the only difference being that weld (b) had about three cycles longer welding time than (a).

Cooling Electrodes

The effective life of the electrodes will depend largely on the efficiency of the water cooling. The water should come to within $\frac{3}{8}$ in. of the tip if possible, and the delivery pipe should come well down into the electrode, thus ensuring a circulation of the water. This is shown in Fig. 31.

Power Required

Some indication of the power required may be given by actual examples.

Sheet, .030 in. Tapping, 8 kVA. Time, five cycles. Weld dia. = $\frac{1}{16}$ in. Sheet, .040 in. to .030 in. Tapping, 30 kVA. Time, five cycles. Weld dia. = .10 in.

Hard Electrode Alloys

As the special electrode alloys are comparatively expensive, it is sometimes worth while making electrodes of hard copper with screwed-on tips of suitable hard alloy (Fig. 32).

The use of copper-tungsten electrodes, as Fig. 33 will permit a lower current density, but it increases the risk of splashing of the brass at the surface, thus making an unsightly weld.

Electrode alloys are available containing cadmium, silver, chromium, cobalt or beryllium. These are much harder than ordinary hard-drawn copper and retain their hardness to a higher temperature. All of them lose their hardness well below red heat, hence the need for cooling as close to the tip as possible.

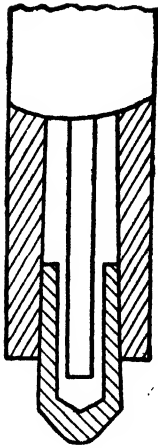


Fig. 31.—WATER COOLED TIP AND HOLDER FOR SPOT WELDING BRASS

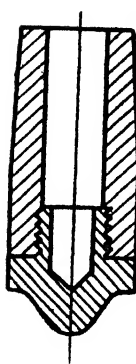


Fig. 32.—ELECTRODE WITH RENEWABLE TIP OF HARD COPPER ALLOY

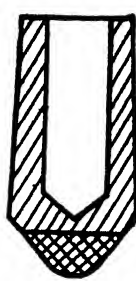


Fig. 33.—ELECTRODE WITH COPPER TUNGSTEN TIP SOLDERED

As tungsten has a melting point over $3,000^{\circ}\text{C.}$, it retains its hardness over all possible welding temperatures.

Welding Plated Brass

Nickel-plated and nickel-chromium-plated brass is easier to weld than plain brass as the electrodes are less contaminated with zinc vapour. The weld is also appreciably stronger.

Cadmium plating reduces the weld strength and increases the risk of failure.

Silicon bronze has a high electrical resistance and a conductivity of about 15 per cent. of copper. It welds readily when clean.

Welding Unusual Copper Alloys

Nickel-copper alloys weld readily.

In welding unusual alloys the effect of the sudden heating and cooling involved in spot welding should be investigated before attempting production.

Projection Welding

Projection welding cannot yet be considered as a practicable proposition on brass. It is possible that it may be used successfully on some of the harder and higher resistance alloys.

Strength of Welds on Copper Alloys

It should be remembered that the weld is a fusion weld rather than a forged weld, as in steel, so that in general the strength of the weld is the strength of the cast alloy.

Welding Brass to Steel

Under suitable conditions good welds may be made between brass and steel, but the welds will not have the strength of a steel-to-steel weld. It should, however, be possible to get sufficient weld strength to pull out a slug of metal from the brass sheet on a test to destruction.

It will be found helpful to use a copper-tungsten or other high resistance electrode in contact with the brass and a high conductivity electrode in contact with the steel. This helps to equalise the heating in the two dissimilar metals.

The same principle may be applied generally to dissimilar metals.

The welding of the copper alloys cannot yet be regarded as an exact science, but is still under development.

Butt Welding Brass

Brass may be butt welded under carefully controlled conditions. Current density, time and pressure must be found by experiment. If the current is too high, the metal at the joint splashes in an explosive way. If the current is too low, there will be insufficient heat at the joint and long heating times will cause heating and softening of the metal on each side of the joint.

Flat brass strip may require more accurate time control than is possible with the usual upset switch, as welding times of three to five cycles may be necessary. The sliding head must be very free, as the brass is burned away very rapidly and the head must follow as quickly, or flashing will result. Flat strip calls for very accurate fitting and alignment of the clamping jaws.

Here, again, a facing of one of the hard copper alloys will prolong the life of the jaws and improve the quality of the weld.

Welders for this work should be of the power-driven fully automatic type, so that a carefully controlled cycle of operations is repeated exactly at each weld.

Chapter VIII

METAL SPINNING

METAL spinning consists of pressing sheet metal into hollow forms in a lathe, by means of various kinds of tools and rollers. The metal receives support on a chuck of suitable contour to mould the desired shape, and before treatment will be either flat or drawn into a shell.

Many articles are only burnished without any formative treatment, while in other cases a drawn object merely has the consequent wrinkles spun down smooth. More than one operation may be necessary in spinning the more difficult examples because annealing has to be performed after a certain amount of work, to prevent cracking. Materials dealt with comprise steel, copper and its alloys, aluminium, zinc, Britannia metal, and silver. Complementary operations are effected on numerous sorts of spun pieces, including trimming, wiring, and beading, as will be explained.

SPINNING LATHES

These are in some respects simply constructed, but must be able to withstand the great stresses produced in spinning.

The Hand Rest

Hand tools are manipulated from a simple T rest, drilled with holes on the top, into any of which a steel pin is inserted to act as a fulcrum for exerting the pressure.

Slide Rest

A compound slide rest controls various tools, and there are rests of special form fitted with rollers and other tools constantly performing the same class of operation.

Driving the Lathe

Belt drive alone is sufficient for a good many lathes; heavy ones require back gear.

Tailstock

The poppets or tailstocks are either simple, with plain or ball-bearing point centre; or of special type, to manipulate the pads which keep the work against the chuck.

Lathes in Action

Fig. 1 represents a lathe by the E. W. Bliss Company, having head-stock spindles running in roller and ball bearings. The tailstocks possess

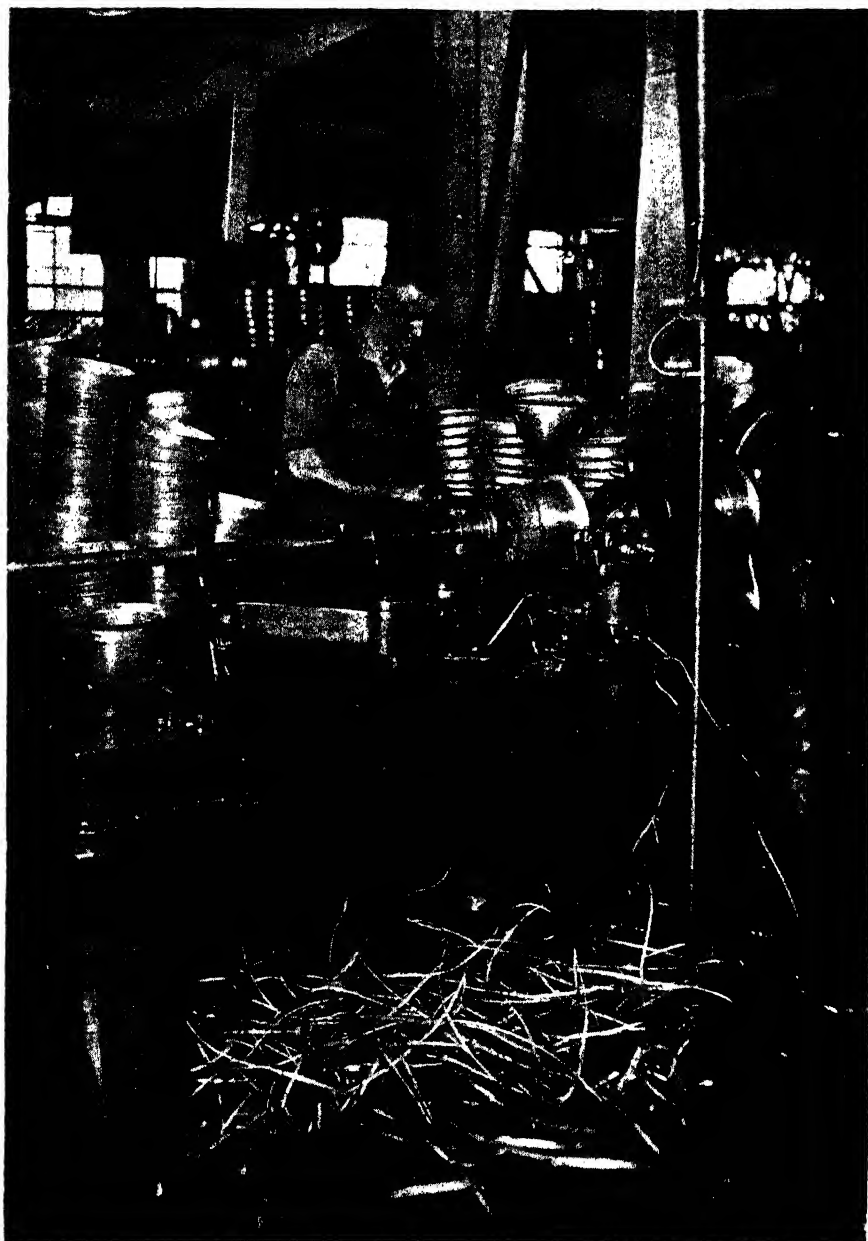


Fig. 1.—OPERATING TRIMMING AND BEADING TOOLS ON ALUMINIUM SAUCEPAN
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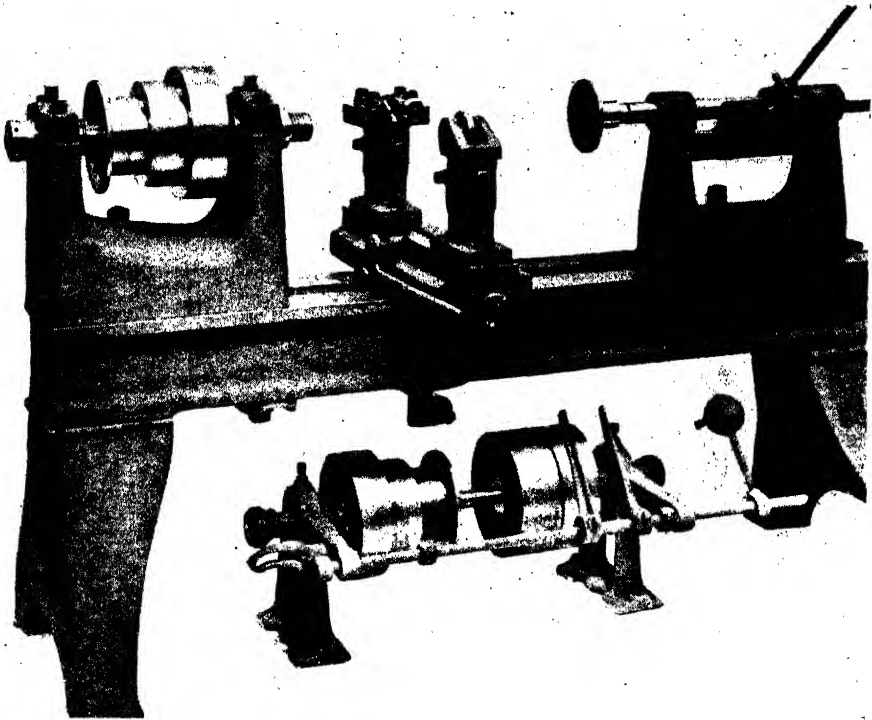


Fig. 2.—SPINNING LATHE ADAPTED FOR TRIMMING AND BEADING WITH LEVER-OPERATED SLIDE (Charles Taylor (Birmingham) Ltd.)

lever-actuated spindles and lock for rapid application. The operations in progress are with sliding rests, the first lathe spinning only, the second trimming edges and beading them over.

Specimens of spun articles may be seen in Fig. 3, these being among the more difficult subjects, involving the use of special devices.

The lathe in Fig. 2, by Charles Taylor (Birmingham), Ltd., takes stampings and trims off the uneven edges, then curling them over. The lever-operated rest carries front and rear tools, and the tailstock has spindle quickly slid and locked by the lever.

CHUCKS

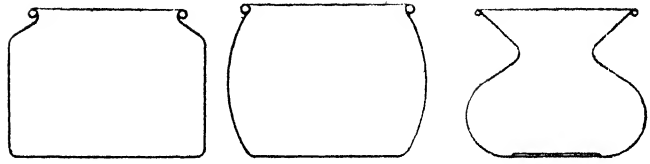
Simple Chucks

For ordinary uses, hardwood is suitable for chucks, and brass or iron for long-continued service.

Fitting Wood Chucks to Lathe

Large wood chucks go direct on the threaded spindle nose, smaller sizes on a taper screw chuck (Fig. 4) of coarse pitch, which fits either on

or inside the spindle nose (see *A* and *B*). *C* is a simple chuck, and the work spun upon it.



Oval Chuck

For spinning elliptical work, as trays, pans, bowls, brush backs, knobs, and so on, what is called an oval chuck has a threaded nose on which the work-holding chuck has to be screwed. The nose being made in one with a slide, this is caused to move in an elliptical orbit through the action of a former ring attached to the front of the headstock. Lateral adjustment to the ring varies the throw. The die on which spinning is done can also be turned up by means of the oval chuck, and a slide rest with tool set exactly to centre height.

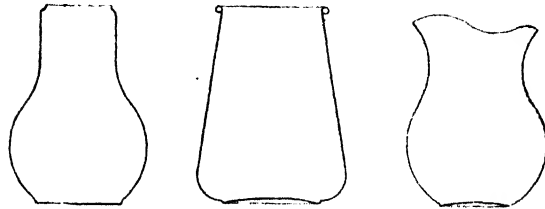


Fig. 3.—METAL-SPINNING WORK

Specimens of articles spun to shape from straight shells

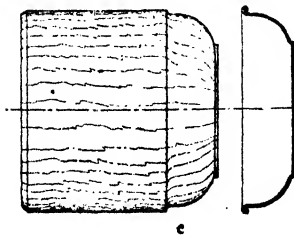
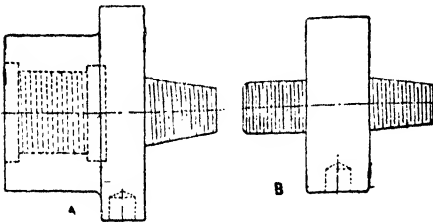


Fig. 4.—CHUCKS FOR METAL SPINNING

A and *B*, taper screw chucks for Taylor spinning lathe. *A* is fitted on spindle nose and smaller chuck *B* is fitted inside spindle. *C*, wood chuck with example of work which is spun on it.

Working with the Taylor Oval Chuck

Fig. 5 illustrates the Charles Taylor chuck. There must be no backlash in the various parts, or a series of flats will be found around the periphery of the work. For accurate and ready adjustment dowel holes and dowels are provided, as lettered on the drawing. The sequence goes as follows :

Set the back plate carrying the former ring *A* central with lathe spindle, and insert dowel peg 1.

Release the four screws *B*, ease back the adjusting screws *C*, and insert dowels 2. Tighten screws *C* until they touch cross-bars *D*.

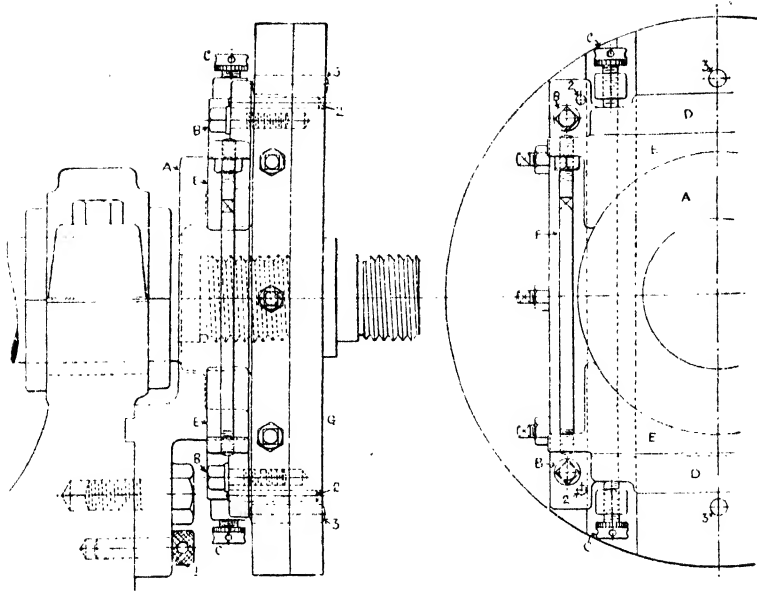


Fig. 5.—TAYLOR OVAL CHUCK

By means of this chuck elliptical shapes are spun.

Insert dowels 3.

Take up any play between the former ring and the gunmetal rubbers *E* by means of rods *F*.

Remove the four dowels 2, turn all four screws *C* through the same number of divisions marked on their heads, thus adjusting the cross-bars *D* parallel and a working fit on the gunmetal rubbers.

Tighten up screws *B*.

Adjust the front slide *G* by means of the gibs and screws.

Remove dowels 3.

Remove dowel 1, and adjust the former ring across to produce the ellipse required. Frequent oiling of the parts is essential.

Loose Poppet for Holding Work in Oval Chuck

In order to hold work in an oval chuck, the style of loose poppet outlined in Fig. 6 is employed; it has lever and link to put on the pressure and the contact pad seen close to the faceplate goes on a spring-fitted rod having ball joints giving freedom of movement.

SPINNING OPERATIONS

Simple Spinning

Ordinary spinning may be seen in Fig. 7, with spinning and burnishing roll manœuvred by slide rest, the shell being held up by the tailstock pad.

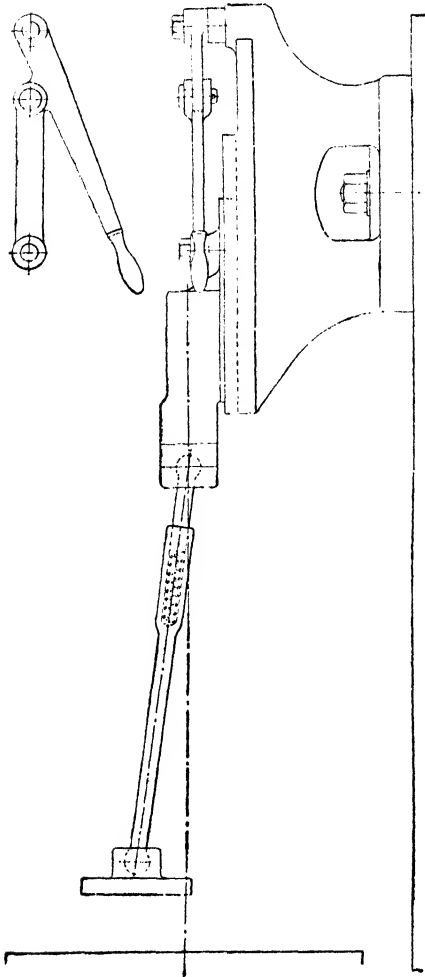


Fig. 7 (left).—ORDINARY SPINNER
With roller controlled by slide rest still being spun to contour of chuck. Original outline shown dotted.

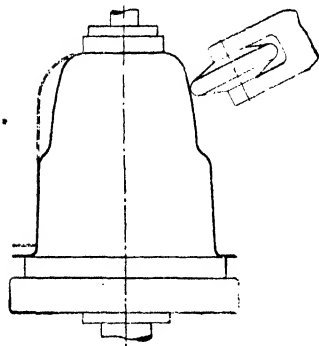
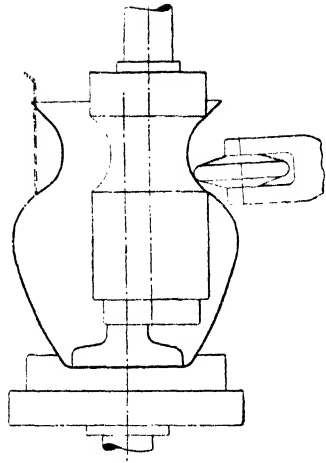


Fig. 8 (right).—A MORE DIFFICULT OPERATION
The neck is supported during spinning by means of a formed roll which is offset by the tailstock.

Fig. 6.—SPECIAL TYPE OF TAILSTOCK FOR USE WITH OVAL CHUCK
Note the spring-pressure rod with ball joints.



The shape of the spinning roll may be modified to suit requirements. The amount that the piece can be changed in one operation is limited by the degree that the metal will stretch without annealing.

Offset Spinning

More difficult handling occurs in Fig. 8, where the problem of the contracted neck is met by utilising an offset tailstock spindle with formed roll, against which the contour is spun with the slide-rest roller as shown. The

tailstock has a cross-sliding adjustment to set the roll out, and retire it after completion of the necking. The bulging of the lower part of the shell has been done at a previous operation.

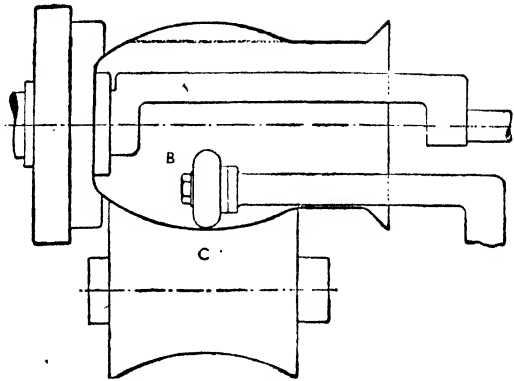


Fig. 9—BULGING FROM THE INSIDE

Roller works on inside while outside of shell is supported against a formed roll which controls contour of shell.

Spinning from Inside

A method of bulging with a roller pressing from the interior is evident in Fig. 9, the dotted line showing the shape before this has been accomplished. *A* is the tailstock pressure arm holding the work into the chuck, *B* the spinning roll carried on an extension arm from the regular compound rest, by means of which it is manipulated. Formed roll *C*, against which the spinning roller shapes the metal, is mounted on a separate post on the bed of the lathe. This roll is necessary to obtain good results in steel; but for aluminium a cam on the bed, which can be followed by a roll or indicator on the cross slide, may be used. Figs. 7, 8, 9 are from practice of the E. W. Bliss Co.

Attachment for Forming Necks

Taylor & Challen, Ltd., Birmingham, have a special equipment for their spinning lathes (Fig. 10), employed to spin necks or close in stampings after leaving drawing presses. The stamping is slipped on the roller *A*, revolving on an eccentric bush *B* with which adjustment can be made for pressure of rolling. Clip *C* fixes *B* on its spindle, while the latter goes in a holder secured to the loose head spindle. After slipping the stamping on the roller, the spindle is driven forward by hand or foot action, thus gripping the piece into the revolving chuck by the pallet plate *D*. Next the spinning roll *E* is operated by the compound rest, until the shape has been spun, the tailstock spindle withdrawn, and piece

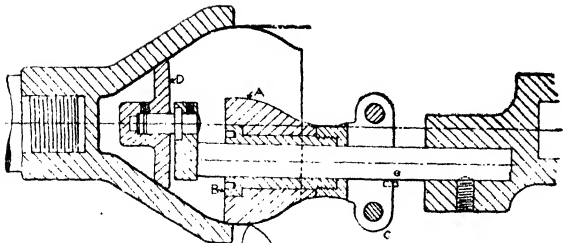


Fig. 10.—COMBINED PRESSURE PALLET AND FORMING ROLLER MANIPULATED FROM LOOSE HEAD

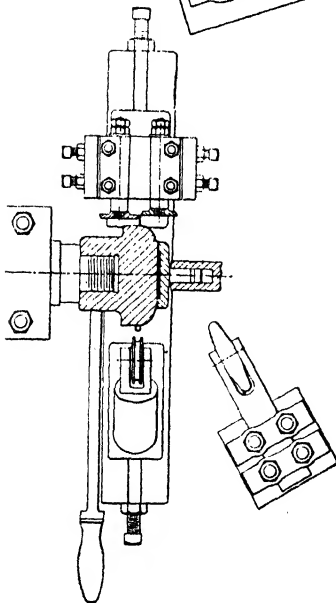


Fig. 11.—SPINNING, TRIMMING, AND BEADING ON ONE LATHE

Spinning roller is on slide rest. Trimming cutters and beading roller are on cross slide.

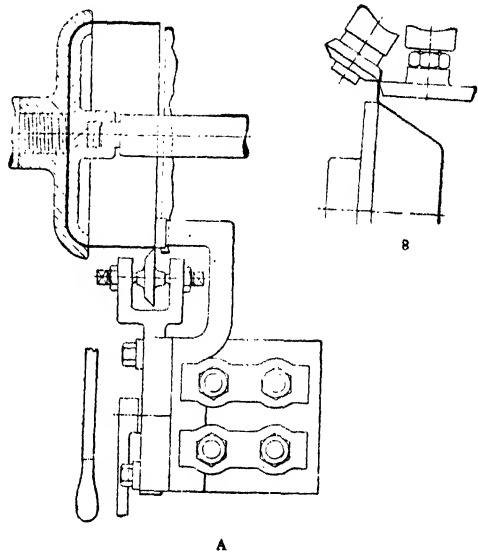


Fig. 12.—METHODS OF TRIMMING

A, lever actuated rest trimming a cup shape after leaving the drawing press. *B*, trimming by means of bevelled cutters which are moved to or from each other.

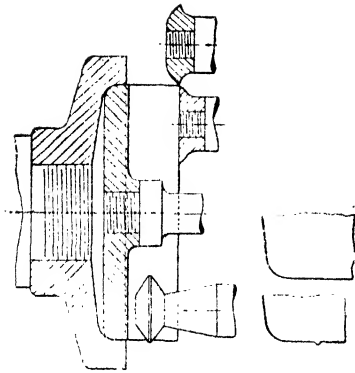


Fig. 13.—TRIMMING AND MARKING
A COVER IN A SPECIAL LATHE

Detail on right shows subject
before and after treatment.

removed, all without stopping the lathe. Roller *A* must be shaped according to how much the metal will stand per operation, two rollers being required for the example illustrated.

Trimming and Beading

These processes are sometimes performed on the same lathe as the spinning, or one operator may spin, and pass the article on to another worker, a single long bed often taking two sets of heads and rests.

Combined outfit (Taylor & Challen, Ltd.) (Fig. 11) mounts the spinning roller on slide rest to the right, and the trimming cutters, and beading (also

termed curling and wiring) rolling on a cross slide fed to and fro by the lever at the left. Stop screws at each end of the cross slide determine the limit of stroke.

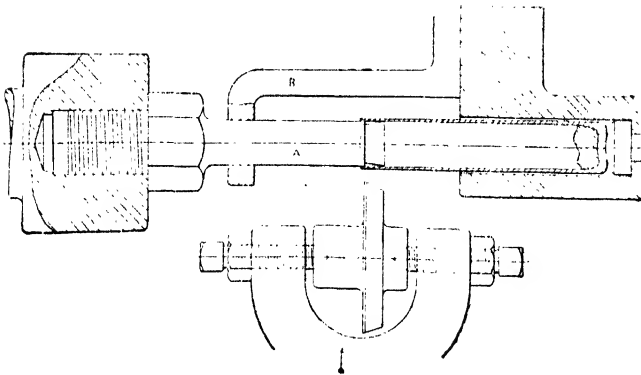


Fig. 14.—ACTION OF AUTOMATIC LATHE FOR TRIMMING CARTRIDGE
CASES BY CIRCULAR CUTTER

Case is pushed on to mandrel *A*, sheared to length, then stripped off by return stroke of *B*.

Trimming Only

Systems of trimming by the same firm may be noted in Fig. 12, *A* dealing with cylinders and cups up to 16 I.W.G., after coming from the drawing press; the top portion of the compound slide rest is shown, and the lever effects the

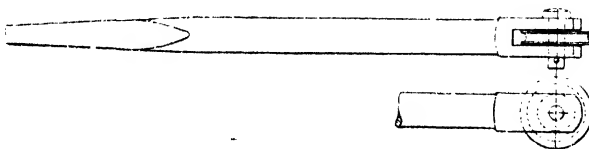


Fig. 15.—TURNING OVER OR WIRING TOOL

With this tool, edges can be finished with a neat curl

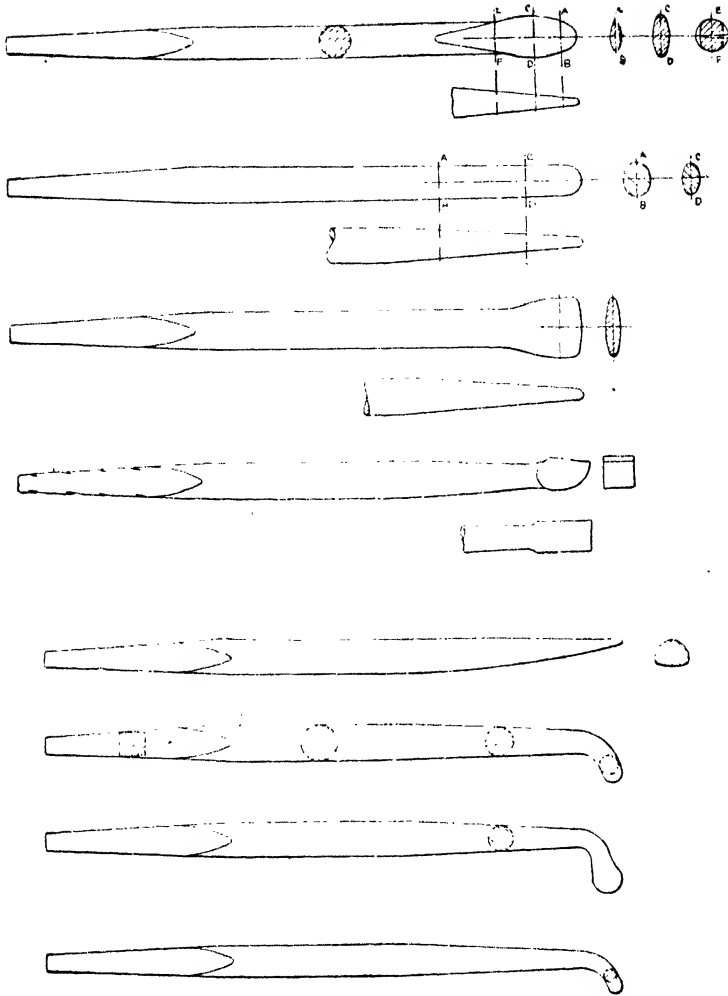


Fig. 16.—SET OF SPINNING TOOLS (Charles Taylor (Birmingham) Ltd.) •

These are fitted in wooden handles and manipulated on a T rest in order to spin and burnish various contours.

operation. The other scheme, *B*, comprises a rest with lever mechanism to move the bevelled cutters simultaneously to or from each other.

Trimming and Marking

Covers for saucepans, oil drums, etc., are trimmed and marked preparatory to the flanging process, by the set-up in Fig. 13, also on a lathe of the foregoing makers. A lever moves the trimming cutters,

together, and another one feeds the marking roller. Toggle mechanism actuated by pedal grips the stamping.

Automatic Trimming Lathe

Fig. 14 gives a plan of the mode of action of an automatic Taylor & Challen lathe, which takes cartridge cases or like objects from a chute by means of a slide, threads them on to a revolving mandrel *A*, ready for the advance of the circular cutter shown. The return movement of the slide causes extractor *B* to strip the trimmed case off the mandrel.

Spinner's Hand Tools

Rather curious tools are used with the hand rest and fulcrum pin previously mentioned. Fig. 16 shows a set furnished by Charles Taylor (Birmingham), Ltd., the first two drawings being of tools with burnished ends, applied variously at the discretion of the operator to spin and burnish straight portions, external and internal curves, bends, corners, etc. These tools are a foot long over all, and go in ordinary wooden handles 15 in. long. Fig. 15 is the roller tool for turning over or wiring, holding a roller of appropriate radius to suit all requirements.

USEFUL TABLES

GAUGES, THICKNESS AND WEIGHT OF BLACK SHEET IRON AND STEEL

(Gauge measured in Birmingham Wire Gauge)

Gauge No. B.W.G.	Thickness in inches	Weight per Sheet		Weight per Sheet		Weight per Sheet		Weight per Square Foot	
		72 in. by 24 in.		72 in. by 30 in.		72 in. by 36 in.			
10	0.125	2 qr.	14 lb.	3 qr.	4 lb.	3 qr.	21 lb.	5½ lb.	0 oz.
11	0.111	2 "	4 "	2 "	19 "	3 "	6 "	5 "	0 "
12	0.099	1 "	26 "	2 "	12 "	2 "	25 "	4½ "	0 "
13	0.088	1 "	20 "	2 "	4 "	2 "	16 "	4 "	0 "
14	0.078	1 "	13 "	1 "	23 "	2 "	5 "	3¾ "	0 "
15	0.069	1 "	8 "	1 "	17 "	1 "	26 "	3 "	0 "
16	0.062	1 "	2 "	1 "	10 "	1 "	17 "	2½ "	0 "
17	0.055	0 "	27 "	1 "	6 "	1 "	13 "	2¼ "	0 "
18	0.049	0 "	24 "	1 "	2 "	1 "	8 "	2 "	0 "
19	0.044	0 "	21 "	0 "	26 "	1 "	3 "	1¾ "	0 "
20	0.039	0 "	18 "	0 "	23 "	0 "	27 "	1½ "	0 "
21	0.034	0 "	16 "	0 "	21 "	0 "	25 "	1¼ "	0 "
22	0.031	0 "	15 "	0 "	19 "	0 "	23 "	1¼ "	0 "
23	0.027	0 "	14 "	0 "	17 "	0 "	20 "	1¼ "	0 "
24	0.024	0 "	12 "	0 "	15 "	0 "	18 "	1 "	0 "
25	0.022	0 "	11 "	0 "	13 "	0 "	16 "	0 "	14 "
26	0.019	0 "	10 "	0 "	12 "	0 "	14 "	0 "	13 "
27	0.017	0 "	8 "	0 "	10 "	0 "	12 "	0 "	10¾ "
28	0.015	0 "	7 "	0 "	9 "	0 "	10¾ "	0 "	9½ "
29	0.013	0 "	6 "	0 "	7½ "	0 "	9¼ "	0 "	8½ "
30	0.012	0 "	5½ "	0 "	6½ "	0 "	8½ "	0 "	7½ "

IMPERIAL STANDARD WIRE GAUGE

(Used for wire and most metals except steel, iron, tinplate, and copper)

Standard Wire Gauge	Equivalent in Inches	Standard Wire Gauge	Equivalent in Inches	Standard Wire Gauge	Equivalent in Inches
1	0.300	13	0.092	25	0.020
2	0.276	14	0.080	26	0.018
3	0.252	15	0.072	27	0.0164
4	0.232	16	0.064	28	0.0148
5	0.212	17	0.056	29	0.0136
6	0.192	18	0.048	30	0.0124
7	0.176	19	0.040	31	0.0116
8	0.160	20	0.036	32	0.0108
9	0.144	21	0.032	33	0.0100
10	0.128	22	0.028	34	0.0092
11	0.116	23	0.024	35	0.0084
12	0.104	24	0.022	36	0.0076

USEFUL TABLES

TINPLATE SIZES, GAUGES (B.W.G.), AND MARKS

<i>Mark on Sheet</i>	<i>Nearest Gauge (B.W.G.)</i>	<i>Thickness in inches</i>	<i>Size of Sheets</i>
1 C	30 B.W.G.	0-012	20 in. by 14 in. and 28 in. by 20 in.
1 X	28 B.W.G.	0-014	
1 XX	27 B.W.G.	0-016	
1 XXX	26 B.W.G.	0-018	
1 XXXX	25 B.W.G.	0-020	
1 XXXXX	24 B.W.G.	0-022	
1 XXXXXX	22 B.W.G., slack	0-027	17 in. by 12½ in. 25 in. by 17 in. 25 in. by 34 in.
DC	28 B.W.G., full	0-015	
DX	26 B.W.G.	0-018	
DXX	25 B.W.G.	0-020	
DXXX	24 B.W.G.	0-022	
DXXXX	22 B.W.G.	0-028	
DXXXXX	21 B.W.G.	0-032	15 in. by 11 in. and 15 in. by 22 in.
DXXXXXX	20 B.W.G.	0-035	
SDC	28 B.W.G., full	0-015	
SDX	26 B.W.G.	0-018	
SDXX	25 B.W.G.	0-020	
SDXXX	24 B.W.G.	0-022	
SDXXXX	24 B.W.G., full	0-023	
SDXXXXX	23 B.W.G.	0-025	
SDXXXXXX	22 B.W.G., full	0-029	

COPPER SHEET (4 ft. by 2 ft.)

(Copper sheets are usually manufactured in one size only, 4 ft. by 2 ft., the thickness not being classified in gauge numbers, but by the weight of the sheet (in lb.). Thus a sheet of copper which is 20 B.W.G. thick is known as "14 lb. copper," this being the weight of a full sheet of this thickness.)

<i>Lb. per Sheet</i>	<i>Nearest B.W.G.</i>	<i>Lb. per Sheet</i>	<i>Nearest B.W.G.</i>	<i>Lb. per Sheet</i>	<i>Nearest B.W.G.</i>
4 lb.	30 B.W.G.	12 lb.	21 B.W.G.	28 lb.	15 B.W.G.
5 "	28 B.W.G.	14 "	20 B.W.G.	32 "	14 B.W.G.
6 "	27 B.W.G.	16 "	19 B.W.G.	36 "	13 B.W.G.
7 "	25 B.W.G.	18 "	18 B.W.G.	40 "	12 B.W.G.
8 "	24 B.W.G.	22 "	17 B.W.G.	44 "	11 B.W.G.
9 "	23 B.W.G., slack	24 "	16 B.W.G.	50 "	10 B.W.G.
10 "	22 B.W.G., slack				

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